WORKSHOP PRACTICE

VOLUME VIII

VOLUME VIII

INTERNAL COMBUSTION ENGINE TESTING

BY

A. W JUDGE, WH Sc, A R C.S, A.M I A E.

STEAM ENGINE AND PUMP FITTING AND ERECTING

TESTING OF STEAM ENGINES

BY

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TURBINE FITTING AND ERECTING

BY

J J STOKES

WORKSHOP PRACTICE

A PRACTICAL WORK FOR THE DRAUGHTSMAN, THE MECHANIC, THE PATTERN MAKER, AND THE FOUNDRYMAN

EDITED BY

E. A. ATKINS

M I MECH E, M I W E.

VOLUME VIII

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WORKSHOP PRACTICE

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PREFACE

In this volume the reader will find a final section on internal combustion engines, where Mr. A. W Judge deals with modern methods of measuring brake-horse-power, compression pressures, engine speeds, and fuel consumption, together with the ways and means of closely observing the behaviour of rotating and oscillating parts, such as valves and valve springs, with recently-evolved instruments such as the stroboscope He also goes on to describe various endurance and performance tests, and he does not neglect to explain fully the functioning and handling of all the various instruments and devices connected with these tests In short, this section is extremely interesting, and merits close perusal by engine fitters, erectors, and others

The remainder of Volume VIII is devoted to steam engine and pump fitting, erecting, and testing, and to the fitting and assembly of steam turbines The author of the steam engine sections has written a very concise and comprehensive series of articles, in which he gives detailed instructions from the purely practical view-points of the fitter and erector Much of the information is given in the form of short notes, which are strictly to the point with no superfluous descriptive matter.

In the section on steam engine testing, numerous

examples of calculations are to be found, dealing mainly with b h p and mechanical efficiency computations

The final section on steam turbines follows closely the lines of the preceding sections, and the lining-out, erection and care of the rotors and their bearings in this special class of steam engine are briefly explained

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INTERNAL COMBUSTION ENGINE TESTING

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SECTION XXXIV

INTERNAL COMBUSTION ENGINE TESTING

THE development of any engine or, indeed, any piece of machinery, is largely a matter of trial and experiment. The designer, aided by previous experience and information derived from the actual performance of other engines or machines, evolves the best design possible under the circumstances The constructor utilizes the best available materials and machining methods in manufacturing the parts of the engine or machine, so that the finished product represents about the best that can be obtained under the existing conditions.

After completion, the engine or machine is given a thorough testing under the most severe working conditions it will be called upon to face, and its behaviour is noted carefully At the same time measurements relating to its performance are made, and the results of these are compared with those of previous or competitive products

Sometimes the engineer will require to know what is the useful length of running life of an engine before overhaul, in order to ascertain the best design, dimensions, and materials for future engines, or on which to base his instructions to users. He will then run the engine under constant load conditions and at its normal working speed until either something happens, or the performance begins to fall off After this the engine will be dismantled and examined carefully to find out the chief sources of wear or non-reliability.

It is only by constantly experimenting with and

testing engines that the engineer is able to make improvements and to develop engines so as to give the best performances, with the smallest fuel consumptions and longest endurances. The history of the development of the motor-car and aircraft engine is an excellent example of the results of trial and experiment.

THE SCIENTIST'S SIDE OF EXPERIMENTING

Some of the experimental work required in the search for knowledge of engine performance, and the causes of certain effects observed during tests, or in the normal working of the engine, requires the skilful knowledge and methods of the scientist. We shall not dwell upon this side of the subject, in view of the present scope and objects of these articles, but in passing it may be mentioned that by careful observation and measurement of such items as pressures, temperatures, fuel consumptions, internal (or indicated) power, detonation pressures and conditions occurring in petrol engines, the scientist has been largely responsible for the progress that has been made in the development of this and similar internal combustion engines.

Special engines, designed primarily for laboratory use, for investigating certain effects, such as compression effect, the use of different fuels, turbulence, cylinder cooling, the use of light but strong steels and alloys, valve size and disposition, crankshaft vibration, and similar factors, have been built purely in order to obtain data and information that can be beneficially employed in the design of commercial types of engine. To quote but one example from many, we have the case of the development of the very large aeroplane engine. It was believed that instead of going in for a large number of cylinders and their associated parts, in order to obtain a large-power output, it would be better, from the point of view of better reliability, to keep the

FIG. 1 THE TRIUMPH SEVEN LIGHT CAR ENGINES UNDERGOING BRAKE POWER TESTS

number of cylinders down to a minimum. The question arose as to the largest size of cylinder that could usefully be employed without giving rise to possible temperature troubles, e.g. valve burning, cylinder distortion, and piston overheating Obviously, it would be an expensive business to build a big engine with super-cylinders, so it was decided to make a single-cylinder engine which could be fitted with various sizes of large cylinders. This was done, and temperature and power measurements, etc , made at various speeds with the result that practically complete information was obtained from which to build the giant large-cylinder engine.

PRACTICAL TESTS: THEIR OBJECTS

Although most engineers and mechanics are interested in the experimental development side of internal combustion engines, they are more concerned with the practical tuning and testing of engines. It is generally recognized, by themselves, that the other side necessitates a good deal of scientific knowledge and experimental skill , in addition, an elaborate and expensive testing equipment is required

The principal tests with which we shall deal relate to the practical bench and road tests of engines, carburettors, and ignition devices, and to workshop or test bench measurements of such items as brake horse-power, compression pressure, engine speed, and fuel consumption Reference will also be made to one or two instruments known as *indicators*, that are now used in several works for examining the internal working pressures of internal combustion engines.

Another useful instrument is known as the *stroboscope* ; it is used for examining the behaviour of rapidly rotating or oscillating parts, such as the valves and valve springs of high speed petrol engines.

There are *two principal kinds of engine test* with which

the internal combustion engineer is concerned, namely, the performance and endurance tests of new designs of engine, and that of re-conditioned engines. It is the manufacturer who is chiefly interested in the former, and the repairer in the latter.

Every reputable make of new motor-car, cycle, or boat engine that is now built is given a performance test to find out whether it comes up to the standard laid down, and an endurance test to discover any possible sources of trouble, before it leaves the works and passes into the hands of the user.

Similarly, the better repair depots, and motor-car overhaul works are now equipped with plant for testing re-conditioned engines for power, speed, and fuel consumption.

As the test procedure adopted for new engines is the more important and, generally speaking, the more difficult, we shall deal, firstly, with the easier and more simple of the workshop methods of testing engines, and thus lead up to the former type

WORKSHOP TESTING METHODS

The ordinary engineering workshop does not generally possess much in the way of testing gear for engines, and as some practical engineers are unfamiliar with the essential apparatus required, we shall describe, briefly, the chief items of equipment that every small engine repair workshop should possess.

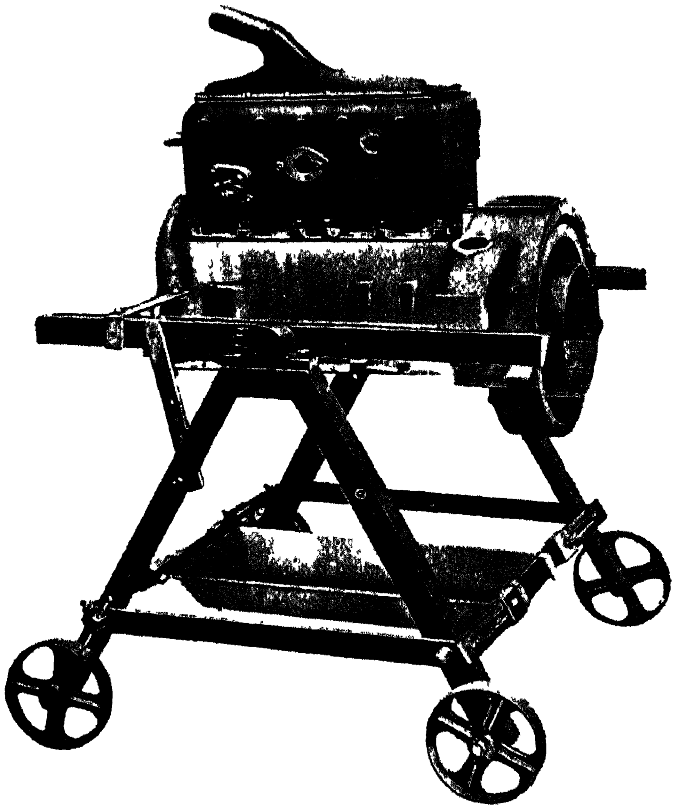
THE ENGINE TEST BED

The first item is the *engine test stand or bed*. It is important to provide a fairly rigid stand, or, better still, a properly designed test bed that will take most of the engines likely to be dealt with. Portable engine stands are now only employed for running in the bearings. Fig. 3 illustrates a typical engine stand that can

Fig. 2. Running-in of Triumph Seven Light Car Engines

Showing the engines being belt-driven around, without firing

be used for running-in purposes Thus, after an engine has been overhauled, its cylinders re-ground, new pistons fitted, and new main and secondary bearings



(Mann-Egerton)

FIG 3 A PORTABLE ENGINE STAND THAT CAN BE USED FOR RUNNING-IN THE ENGINE

fitted, it is usual to motor the engine around for a few hours, with the ignition " off " and the sparking plugs removed, in order to allow the bearing surfaces to " bed " down properly After bearings and shafts, or

cylinders and pistons have been machined and finished in the best possible manner, examination of the bearing surfaces under a microscope will show a series of "hills and furrows", these are the marks left by the finishing stone or tool.

After the engine has been run for a certain period—usually about 24 hr.—these "hills" are smoothed down and the surfaces attain their best possible working condition for rubbing or sliding contact.

It is for this reason that the manufacturers of "mass produced" cars and cycles, being unable to afford the time or expense of running-in each engine before it leaves their works, send out their cars or cycles with the instructions that, for the first 500 miles or so the road speed on top gear should not exceed 25 miles an hour, and on other gears correspondingly lower speeds The purchaser is thus made to do the running-in test.

With the engine stand illustrated a belt pulley can be fitted to the engine crankshaft, the stand raised off its wheels, and the engine belt-driven from an electric motor or from the line shafting for the appropriate running-in period

For actual running tests a rigid engine test bed is necessary. Most firms build their own beds from suitable angle and channel steel, bolted together and firmly secured in a heavy concrete bed. Fig. 4 illustrates a simple form of test bed made from channel steel, and bolted down to a concrete foundation. In this case the engine bearers are bolted to the channels *A*, the latter being in turn bolted down to a pair of parallel tees *B* running transversely, and bolted down to the concrete bed *C*.

For different types of engine, the distance between the two channels will have to be altered; this will necessitate drilling fresh holes in the "T"-section steels *B* Also, it may be necessary to raise or lower the

engine so as to give the correct alignment of its crankshaft with that of the motor, dynamo, or brake used for testing purposes The usual procedure is to employ packing strips, as indicated by the dotted lines *F* (Fig 4)

In the majority of cases where only one type of engine is tested it is a matter of simple design to arrange a suitable fixed or permanent type of test bed, on which engines can rapidly be bolted down and, after

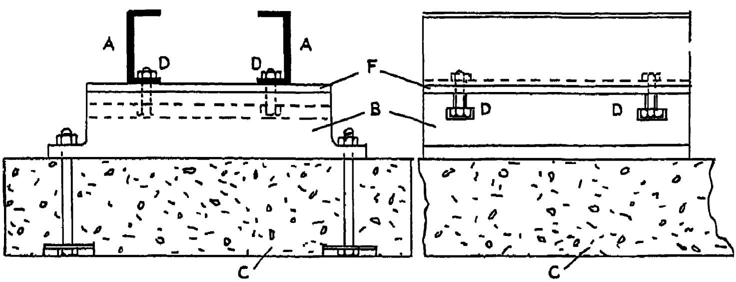


FIG 4 ARRANGEMENT OF CHANNELS AND BASE CASTINGS FOR ENGINE TEST BED

the tests, removed. The mass production works is usually provided with a testing section equipped with a number of specially designed testing stands, complete with engine bearer rails, fuel, and water supply test instruments, and means for measuring the power A typical case is that of the Morris engines, which are provided with somewhat elaborate testing stands.

For motor-cycle engine tests, the engine can be held in a simple pair of metal plates *A* (see Fig. 6) similar to those employed in holding it to the motor-cycle frame These plates are bolted to permanent test bed angle or channel plates *B*, so that it is only necessary to change the smaller plates *A* when another pattern of engine is employed. The test bed members *B* are held rigidly in a concrete foundation bed. For convenience

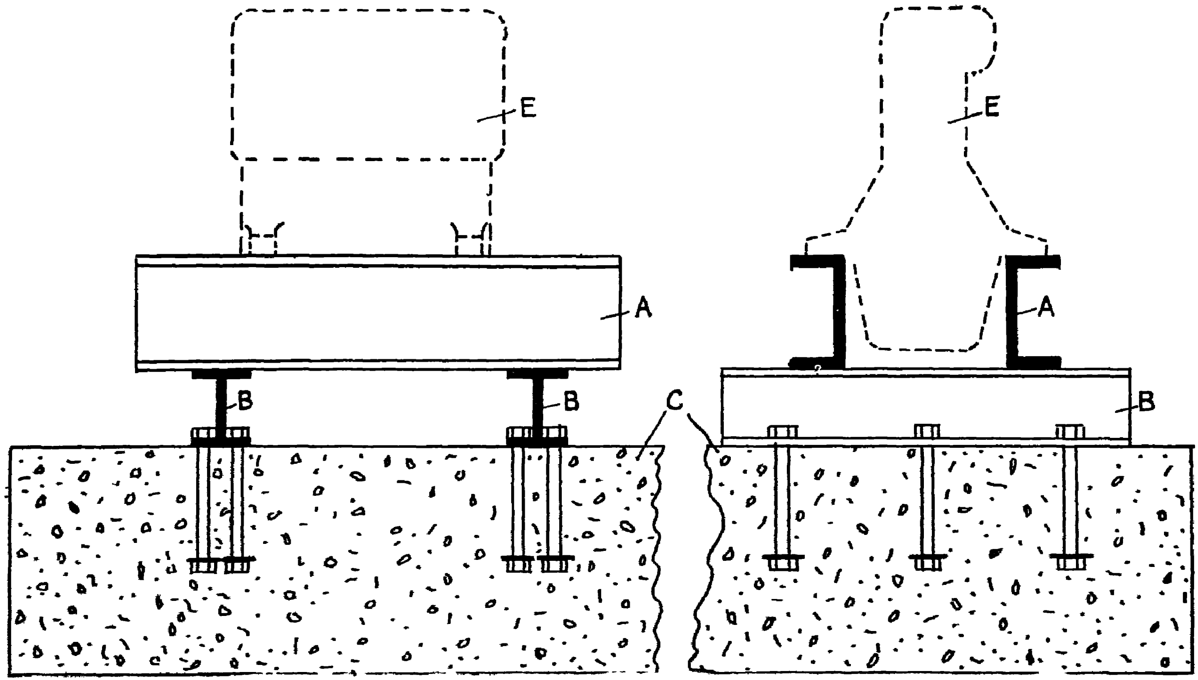


Fig 5. An Improved Engine Test Bed on Concrete Base

This arrangement allows various types of engine to be tested on the same bed

of test the engine crankshaft centre should be about 2 ft to 2 ft 6 in above the ground.

FUEL ARRANGEMENTS

Having settled the matter of the engine test bed, it is next necessary to make suitable provision for the

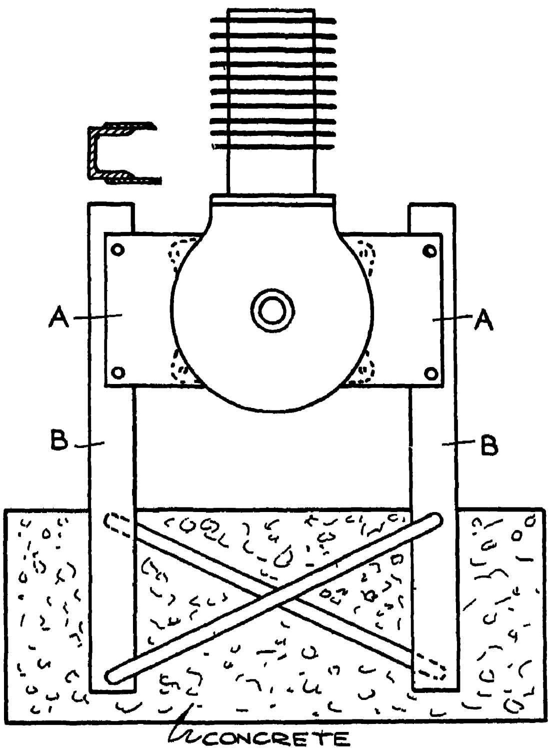


FIG. 6. A SIMPLE MOTOR-CYCLE TEST BED

supply of petrol, and, where fuel consumption tests have to be made, to arrange for measurements of the fuel used during certain periods of running. In either case it will be necessary to employ a petrol or fuel tank

placed above the level of the carburettor, so that the fuel flows down to the latter by gravity Assuming it is required to measure the fuel consumption of the engine in the simplest possible manner, and with apparatus

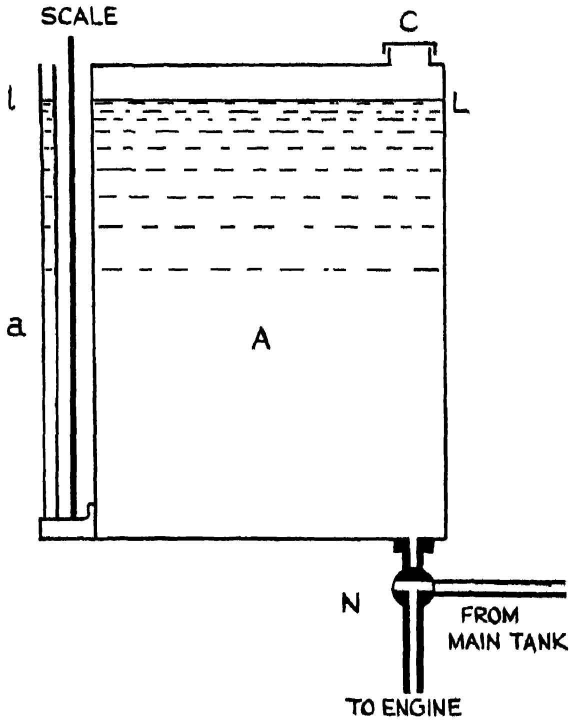


FIG. 7. ONE METHOD OF MEASURING FUEL CONSUMPTION

capable of being rigged up in any workshop, probably the best arrangement is one on the lines indicated in Fig. 7 In this case a tinned steel or copper tank *A* of suitable capacity for the type of engine to be tested is provided with a glass gauge *a* having a scale behind it. There is a filling cap *C* and a feed tap *N* leading to the carburettor. The tank *A* is calibrated by pouring

known quantities of fuel, say, 1 pt at a time, and noting, or marking the scale behind the glass gauge *a*. In this way the quantity of fuel corresponding to each division on the scale is known accurately If the tank is made rectangular in section and uniform, it will only be necessary to first pour in fuel until its level is just shown at the bottom of the gauge, and then to pour in sufficient fuel to reach another mark near the top of the gauge, noting the quantity used It is then an easy matter to mark the scale For example, if 8 pt. of petrol are poured in to raise the level from the lowest gauge mark to the highest one, and the distance between the two marks is 20 in , the quantity of petrol corresponding to each inch on the scale will be $\frac{8}{20}$, or 0·4 pt If it is required to mark the scale in pints and fractions, then the distances between the pint marks on the gauge scale will be $\frac{20}{8}$, or $2\frac{1}{2}$ in The half pint distances will be $1\frac{1}{4}$ in , the quarter pints $\frac{5}{8}$ in., and so on

To make a fuel consumption test on an engine it is very important to have the engine thoroughly warmed up to its normal working temperature, by running it for a certain period beforehand If it is a water-cooled engine it should be run until the water is warmed up to its usual working temperature, and the crankcase oil is also at its working temperature

It is further essential, during a fuel consumption test, to see that the engine runs perfectly uniform and at a constant speed—as shown by a speedometer or tachometer driven by the engine. The load on the engine should therefore be kept constant, and means provided for altering the value of the load for regulation purposes. Here it should be mentioned that the load on an engine under test is supplied by a power-absorbing device known as a *power brake*; an account of some of these brakes will be given later.

Supposing the fuel consumption of an engine is required at one-quarter load, the brake would be adjusted until it absorbed one-quarter of the greatest power developed by the engine and previously measured. The speed would be noted, and the engine would be kept running at this speed during the test.

To come to the test itself; having suitably arranged the engine load and controls for the test in question, and allowed the engine to run sufficiently long to reach steady working conditions, the fuel supply from the main tank is switched off by means of a two-way tap *N* (Fig 7), and that of the measuring tank switched on; if this is done quickly there will be no stoppage of fuel supply. As the level of the fuel in the tank *A* begins to fall, it will reach a certain mark *e* near the top of the scale At this point a note should be made of the time; a stop-watch is better, however, it being only necessary to start the watch When the engine has run for at least 5 min. under the constant conditions of the fuel, the reading on the gauge scale should be noted carefully, and the time also taken or the stop-watch "stopped." It is best to wait until the fuel just reaches the nearest scale graduation and then to take the second time reading; this simplifies the subsequent calculation and increases the accuracy.

As an example, supposing that it has taken 10 min. for the level of the petrol to fall from the 3 pt. to the $1\frac{1}{2}$ pt mark on the scale. Then $1\frac{1}{2}$ pt. of fuel will have been used in 10 min, so that in 60 min. $\frac{60}{10} \times 1\frac{1}{2} = 9$ pt. $= 1\frac{1}{8}$ gal. of fuel would have been used

Supposing that the engine during the test was giving 20 b.h.p, then the *fuel consumption per b.h.p.* per hour would be given by the expression $\frac{9}{20} = 0{\cdot}45$ pt. This s the usual method of expressing and comparing fuel consumptions of engines.

An improvement on this method, however, is to

express the result in weights (or pounds) instead of volumes or pints.* The best measured fuel consumptions of petrol engines, namely, aircraft and automobile types are of the order 0·45 to 0·50 lb. of petrol per brake horse-power

In connection with the size of the fuel-measuring tank for testing engines this need not be very large, as fuel consumption tests are usually of short duration, namely, of a few minutes only If it is remembered that only about 1 pt of petrol is used by a 20 h p. engine running at full throttle, during a 5 min run, a good idea of the appropriate size of measuring tank will be obtained for any other engine

An improved fuel measuring device is shown in Fig 8 In this case there is a main supply tank *M* of several gallons capacity, as a rule, and a small glass cylindrical vessel *S* of fairly small capacity, say, 1 pt in the case of a 20 to 30 b h p engine The glass cylinder is cemented into a metal base so as to be petrol-tight, and is connected by a short pipe to a two-way cock *C*, so arranged that petrol can be fed to the engine either from the main tank *M* or the measuring vessel *C*

In making a test with this arrangement, the engine is run from the petrol in *M* until it has warmed up thoroughly. The vessel *S* having previously been filled with petrol, the cock *C* is now switched over so as to feed the engine from *S* When the petrol falls just level with a mark *a* on the glass vessel a stop-watch is started, and when it drops to the mark *b* below, the watch is stopped We have then the time taken for the known quantity of petrol corresponding to that between the marks *a* and *b* to be used by the engine, and, as in the previous case, are able to work out in a simple manner the petrol consumption of the engine

* A gallon of petrol of 0 72 specific gravity weighs 7 2 lb

It is usual when making accurate tests of fuel consumption to make a note of the temperature of the fuel, for the volume of a given weight of fuel depends upon

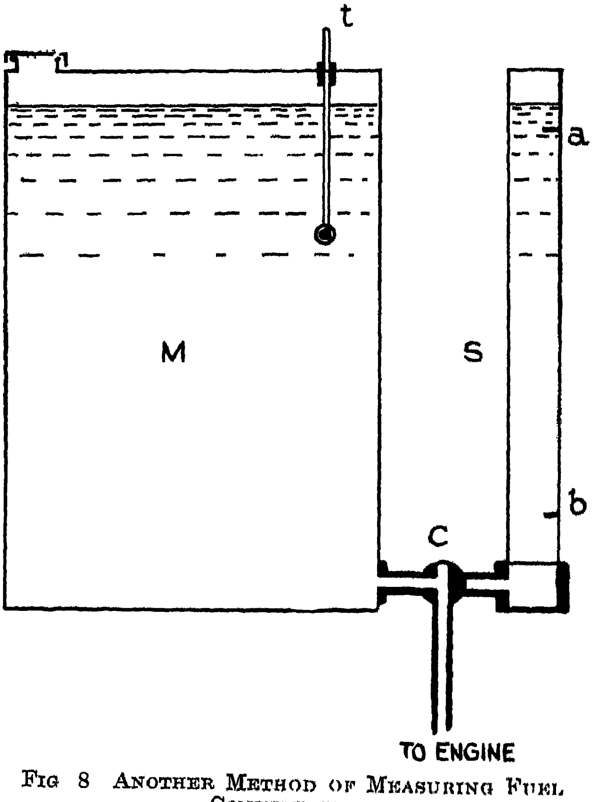


FIG 8 ANOTHER METHOD OF MEASURING FUEL CONSUMPTION

This employs a graduated glass vessel *S*

its temperature, the volume being greater as the temperature rises. Knowing the expansion rate of the given fuel, a correction for temperature can be made in the results. In Fig. 8 the thermometer is shown at *t*. In order to simplify fuel tests it is better to arrange the

two marks *a* and *b* (Fig 8), so that the distance between these two levels represents exactly 1 pt of

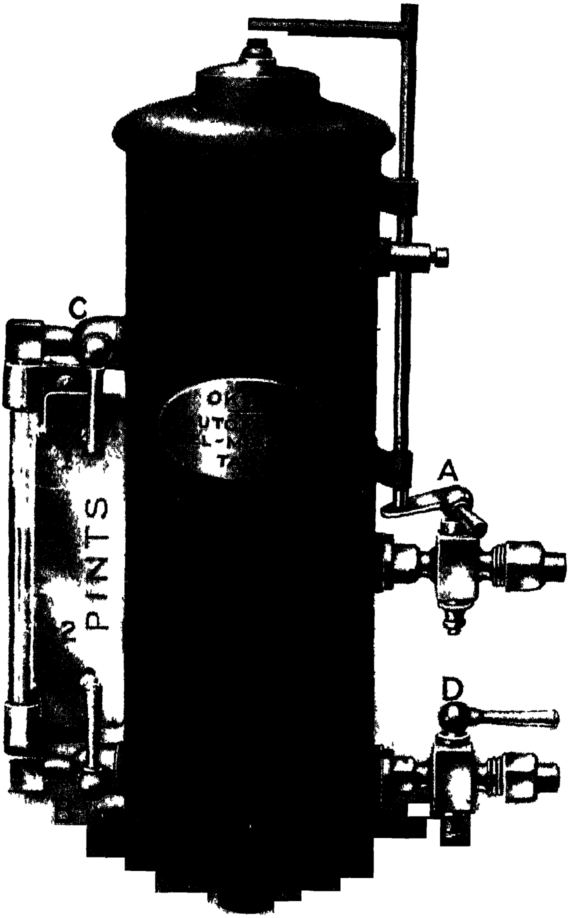


Fig 9 The Okill Fuel Consumption Apparatus

petrol, or whatever fuel is used, at the average workshop temperature. The fuel consumption tests of engines

are for comparative purposes, generally made at full throttle—or full load.

To those who do not wish to make their own fuel

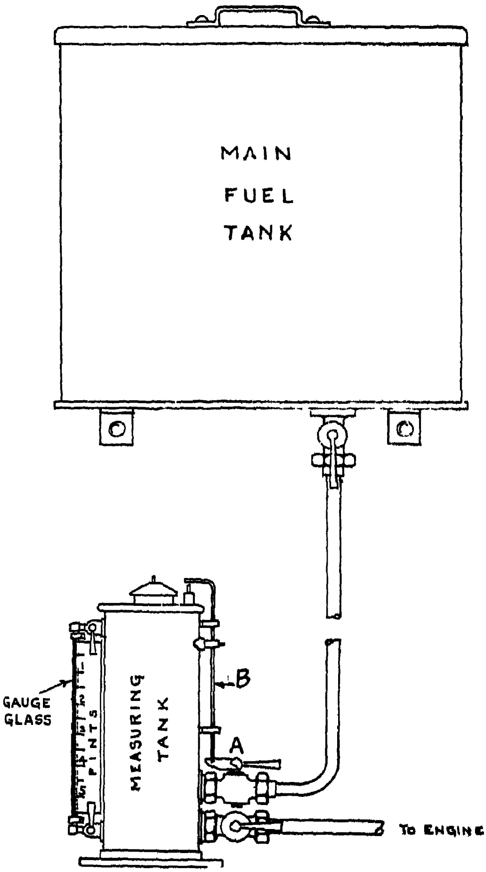


FIG 10 SHOWING THE PRINCIPLE OF THE OKILL FUEL CONSUMPTION MEASURING APPARATUS

measurement apparatus, there is now available on the market several types of fuel-measuring devices,

conveniently arranged for connecting to the engine and for making tests

Fig 9 shows the Okill arrangement supplied by Messrs G Taylor of Bolton It comprises a reservoir of suitable size for a test run of 4 min , fitted with inlet and outlet cocks *A* and *D* respectively, and glass gauge cocks *C* and *B* A float-operated valve at the top is provided to allow the air to escape when filling the tank, and to enter when the engine is running on the fuel in the tank ; this valve controls also the amount of fuel admitted to the tank in an accurate and automatic manner The fuel consumption of an engine is measured by starting a stop-watch when the cock *A* is closed and stopping the watch when the cock *B* is closed at the end of the test The amount of fuel consumed is then read off in pints on the gauge The cocks *A* and *B* are then opened and the measuring tank allowed to fill again This form of fuel consumption measuring device can also be obtained for use with Diesel engine fuels

Fig 11 illustrates the simple apparatus made by Brown & Barlow for checking fuel consumptions It is calibrated in pints

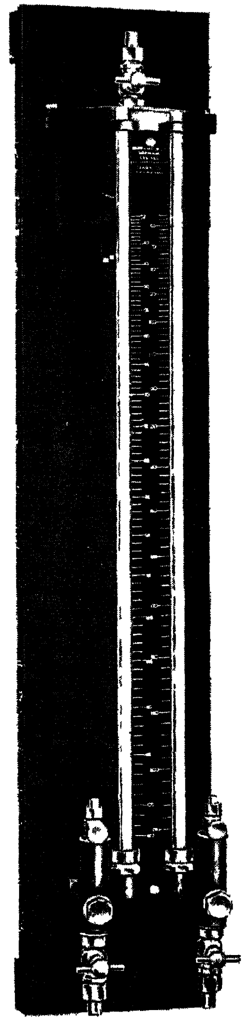


Fig 11 Brown and Barlow Flowmeter for Registering Fuel Consumption

per hour Another method of measuring fuel consumption, used in the United States, employs the principle of weighing the fuel used The fuel tank is arranged on a weigh-bridge, the weighing arm of which is arranged to make electric contacts when the test commences and finishes, so as to record the total number of engine revolutions and also the time of the test. This arrangement, it will be noted, is automatic, and can be made fool-proof

FUEL FLOWMETERS

The methods we have previously described require a certain time interval, and therefore give the average fuel consumption over this period of time. It is therefore necessary to wait for a few minutes in each test, before one can ascertain the fuel consumption During this period conditions may alter, and the results obtained will not then be accurate. To overcome the above drawbacks a type of instrument, known as a *flowmeter*, has been devised to read off the actual fuel consumption, or rate, so that it gives instantaneous readings. It depends in principle, upon a method of indicating *the rate at which the fuel is flowing* into the carburettor or engine

The working details of flowmeters are usually not simple, and we shall not therefore describe any proprietory make. Instruments of this type are supplied by firms such as Messrs. Brown & Barlow, Birmingham, and Elliott Bros, Ltd., London.

ROAD TESTS OF FUEL CONSUMPTION

It is often required to ascertain the fuel consumptions of engines fitted to road vehicles under normal working conditions, and, in such cases, although the results

obtained are not so accurate as those from bench tests, the methods have the advantage of simplicity.

Before mentioning one or two fuel-measuring devices on the market, an outline of the usual procedure for approximate fuel consumption measurements will be given

Perhaps the simplest method is to arrange for the vehicle to stand on a level piece of ground before the test, and to fill the petrol tank to a given mark on a metal depth gauge, or rod, inserted through the filler cap of the petrol tank The vehicle is then driven for a certain distance, say, 10 to 20 miles, returning to the original piece of level ground, and the fuel tank again filled to the given mark on the depth gauge, noting carefully the actual amount of fuel that has to be poured in to bring the level to the given mark The distance the vehicle has travelled having been recorded on the trip dial or scale of the speedometer, we have all the information for working out the average fuel consumption of the vehicle under normal running conditions

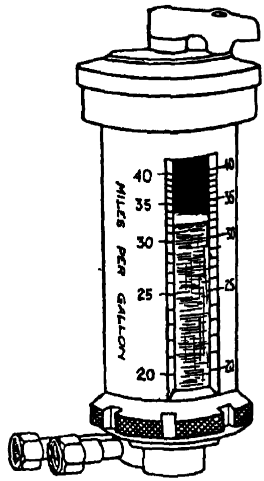


FIG 12 THE GALOMETER FUEL TESTING DEVICE FOR ROAD TESTS

Suppose, for example, that a 5 ton lorry, after travelling 15 miles, requires 13 pt of fuel pouring into its tank in order to bring the level to the original gauge mark. Then the fuel consumption, in miles per gallon, will be $\frac{15}{13} \times 8 = \frac{120}{13} = 9{\cdot}23$

In some cases a small gravity tank similar to the Okill type previously described is fitted to the dashboard, and the readings of a glass gauge taken simultaneously with those of the speedometer mileage. In other cases

the amount of fuel used whilst the vehicle travels a certain number of miles, as noted from milestones or known road marks—afterwards measured on a large-scale map—is measured.

It is best to keep the speed of the vehicle at some constant value and to avoid the use of the brake and clutch as far as possible , in this way some useful information concerning the fuel consumptions at various speeds will be obtained, from which the most economical speed can be ascertained

It is not advisable when making road tests to rely on the readings of the petrol gauge usually fitted to the tank or instrument board, as these are generally inaccurate

Some useful tests can be made over a measured mile on a fairly flat road, and in this case for cars of between 10 and 20 rated horse-power, the capacity of the dashboard fuel measuring tank need not exceed ½ to 1 pt

A useful instrument for making fuel consumption tests in the case of cars fitted with the vacuum method of fuel supply, is that known as the Galometer (supplied by The Autovac Manufacturing Co , Stockport). The instrument in question consists of a circular dial having two indicating panels, one for recording the total fuel consumption up to 1000 gal., the other for " trip " or separate 10 gal. A special type of vacuum feed tank is employed, known as the Measuring Autovac. The Galometer actually records the amount of petrol passing into the Autovac tank ; it indicates the amount of fuel taken in and delivered to the outer chamber of the vacuum tank every time the mechanism operates.

OIL CONSUMPTION TESTS

It is important in the case of new engines or re-conditioned ones, to know, with reasonable accuracy

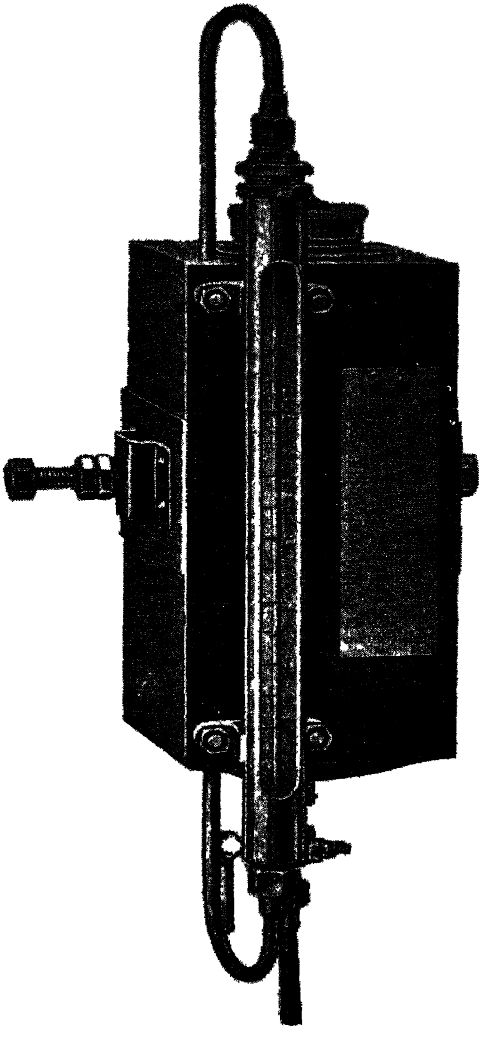


FIG. 13 THE M E FUEL TESTING TANK FOR AUTOMOBILES

what the oil consumption is. In the case of engines used for industrial purposes, minimum oil consumption is essential from both the point of view of economy and maintenance.

There are various methods of testing oil consumption, some of which necessitate scientific accuracy, whilst others are of a practical nature giving approximate results only.

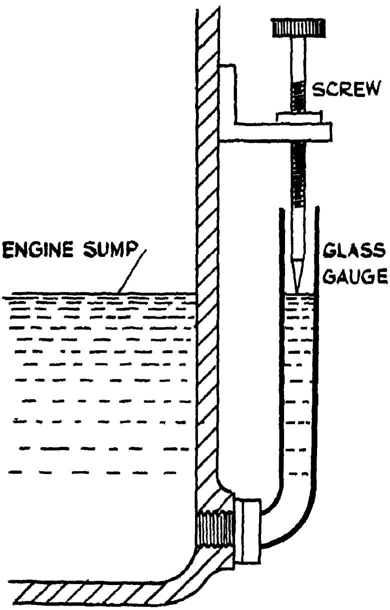


FIG. 14 AN ARRANGEMENT FOR OIL CONSUMPTION TESTS

Let us suppose that we wish to ascertain how much lubricating oil a petrol engine of the four-cylinder car type is consuming. The procedure for approximately accurate results is as follows. When the engine is hot, run out the oil in the engine sump, allowing it to drain out for at least ½ hr. Replace the sump plug, and when the engine is cool pour in fresh oil until the level just reaches a given mark at about the "full" level position. Although the usual float or dipper rod gauge can be used, another method is to fit an outside glass gauge of about ½ in. inside diameter to read against a scale. A still better method is to use a screw-down pointed indicator, adjusted initially so that the point just breaks the surface of the oil. The screw is then left undisturbed until the end of the tests.

It is necessary to run the engine for at least 20 hr for an oil consumption test, since with modern engines the oil consumption is, relatively speaking, so low that no accurate measurement is possible for shorter periods A modern 12 h p car engine will run for at least 50 hr. on a gallon of oil, and as the surface area of the sump is large, the depth of the oil to be measured is relatively small—usually a matter of 2 to 4 in At the completion of the run, the working conditions being kept constant during this period the engine is allowed to cool down, and fresh oil of the same grade and temperature as before is poured in slowly until the original level in the gauge, or of the screw-point, is reached The amount of oil that has to be poured in is equal to the amount consumed.

Supposing, for example, 3 pt of oil were poured in, and the period of the previous test was 25 hr., then the oil consumption would be $\frac{3}{25 \times 8} = \cdot015$ gal. per hr. If the horse-power of the engine, as measured during the tests, was 15, then the oil consumption per horse-power hour would be $\frac{\cdot015}{15} = \cdot001$ gal , or $\cdot008$ pt

It is usual to compare the oil and fuel consumption of different engines by expressing the results in terms of the horse-power hour A more elaborate method of oil testing is to have a vertical gauge glass connected to the base of the oil sump, and to provide it with a scale marked in pints and decimals of a pint, the scale being calibrated by pouring known quantities of oil into the sump and marking the scale accordingly , the oil used can then be read off direct. It is not always an easy matter, however, to read an oil level as the glass becomes greasy and obscures the meniscus.

It may be of interest to mention that the oil consumption of a well-designed petrol engine in new

condition, or after it has been properly "run-in," works out at about ·005 lb. of oil per horse-power hour. Thus, a 20 h.p. engine, i.e an engine giving 20 h.p. maximum on the brake should give an oil consumption of $20 \times \cdot 005 = \cdot 10$ lb. per hr., or about $\frac{1}{10}$ pt. per hr.

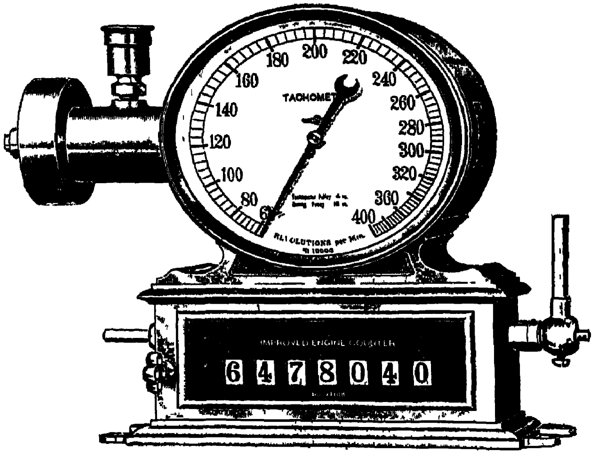
It is most important when carrying out oil consumption tests to measure the oil at the same temperature both before and after the tests, and preferably when the engine is cold Always allow plenty of time for the oil to settle to its final level in the engine, and keep the engine, during the test, running under its normal speed and load conditions.

In the case of motor-cycle and boat engines having drip feed lubrication, it is a fairly simple matter to fix up a small oil tank and gauge, to show the oil consumed as the test progresses.

MEASURING ENGINE SPEEDS

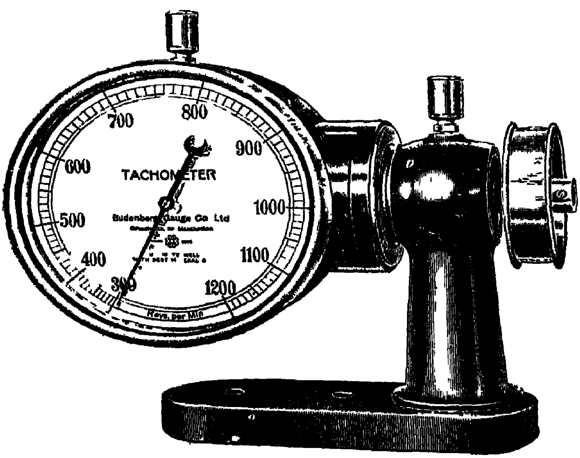
When making tests of engines it is always desirable to have a record of the engine speed ; usually tests are made at a given speed, and the load is regulated to keep the speed constant. If it is intended to measure the average speed during the period of a test, it is best to employ a revolution counter such as the Budenberg instrument (Fig 15) to give the total number of revolutions, say, N, during the test period of T minutes. The average speed is then obtained by dividing N by T, the result being in revolutions per minute.

For keeping a check on the engine speed and for measuring its value at any moment, an instrument known as a *tachometer* (Fig. 15 and 16) is employed. This usually contains a pair of hinged weighted arms that fly out by centrifugal action as the speed increases, the amount of their outward movement being communicated to an indicating needle working over a circular



(*Budenberg*

FIG 15 A COMBINED TACHOMETER AND TOTAL REVOLUTION COUNTER



(*Budenberg*)

FIG 16 A CONVENIENT TYPE OF TACHOMETER FOR ENGINE TESTS

scale graduated to read speeds in revolutions per minute.

The tachometer is generally driven off the blind end of the engine shaft, or by means of a belt and pulleys from any convenient part of the engine shaft, in the latter case the pulleys should be of equal diameters, and means provided for obviating belt slip Chain wheels and a chain are sometimes used where a positive drive is essential

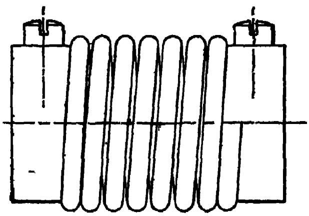
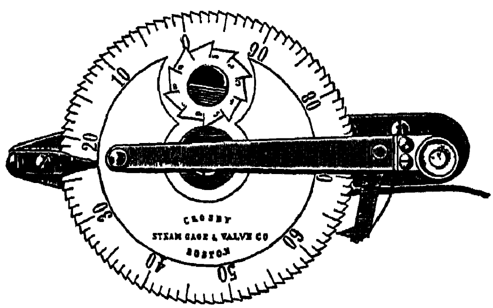


Fig. 17. A Useful Form of Spring Drive for Tachometers and Revolution Counters

If the tachometer is driven off the end of the engine shaft a flexible coupling should be used to prevent any possible damage from non-alignment of the engine and tachometer shafts Sometimes a short length of stiff spiral spring is used as a coupling means.

Fig. 18 illustrates another type of revolution counter that is worked by any reciprocating member of the engine It can usually be arranged to obtain a to-and-fro movement from, say, the cross-head of a Diesel engine, or from a stud placed at a radius on one of the rotating members. A movement of $1\frac{1}{2}$ in. is required to move the larger disc through one tooth or division, and the smaller toothed wheel indicates hundreds of divisions.



(Crosby)

Fig 18 A Simple Revolution Counter

COOLING WATER ARRANGEMENTS

Where tests on petrol, oil, or gas engines are carried out as a routine procedure it generally pays to install a proper system of cooling water, wherewith a wide range of engine sizes can be dealt with satisfactorily.

A suitable arrangement is that shown in Fig. 19 The

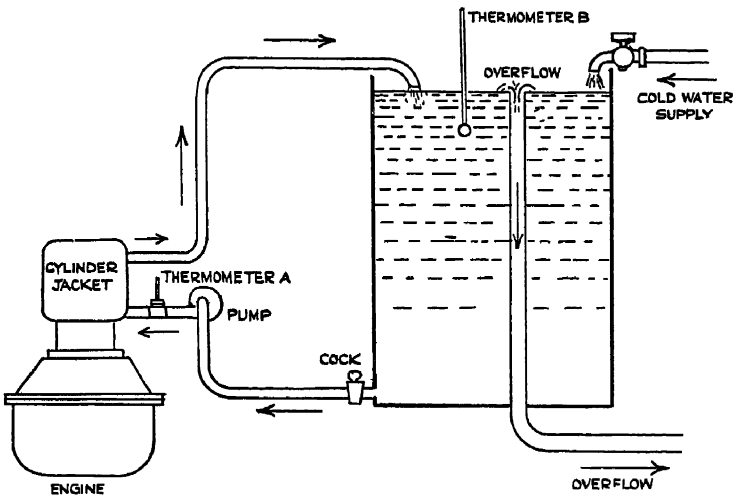


FIG 19 A GOOD METHOD OF CONTROLLING THE COOLING WATER TEMPERATURE

engine water jacket is connected through suitable piping, with rubber connections, to the base and top of a fairly large galvanized-iron tank The capacity of this tank should be about four to five times the usual radiator and cooling system of the largest engine tested, a 20 gal tank is suitable for a 15 to 20 h p petrol engine A circulating pump draws cold water from the base of the tank and delivers it to the lower water connection of the cylinder jacket, a thermometer *A* shows the temperature of this water, whilst another *B* gives the outlet temperature It is best to place the

thermometer B as near the outlet water pipe on the cylinder jacket as possible ; otherwise the water may boil without one knowing it.

By means of a cold water supply tap and an overflow pipe, it is possible to regulate the temperature of the water to any desired maximum value. To facilitate the warming-up of the engine, the water in the tank may be heated independently by means of a gas or oil flame

MEASURING THE COMPRESSION

The term "compression" in internal combustion engine work is somewhat loosely employed. It may denote the compression ratio, or the compression pressure.

In making accurate tests on new types of engines it is important to know the compression ratio, since the performance of the engine varies with this ratio.

Let us explain what is meant by compression ratio. Referring to Fig. 20 representing in outline an internal combustion engine cylinder, with the piston P at the bottom of its stroke, namely, at $A\,A$, after one-half a revolution the piston reaches the top of its stroke at BB, and in doing so sweeps out a certain volume, known as the stroke volume , this is the volume of a cylinder of area equal to the piston area and of height equal to the stroke. Expressed mathematically, it is $\pi \frac{d^2}{4} . S$. The volume C of the combustion chamber above the upper piston position BB is termed the clearance volume, and the *compression ratio* is the total volume of the cylinder above $A\,A$, to the clearance volume C. In other words, the compression ratio

$$= \frac{\text{Stroke volume} + C}{C}$$

One can therefore measure the compression ratio simply by measuring the combustion space volume C

when the piston is on top centre, for the stroke volume is readily estimated from the bore and stroke dimensions

For example, in a certain car engine, the volume C was found by measuring the quantity of oil that had to

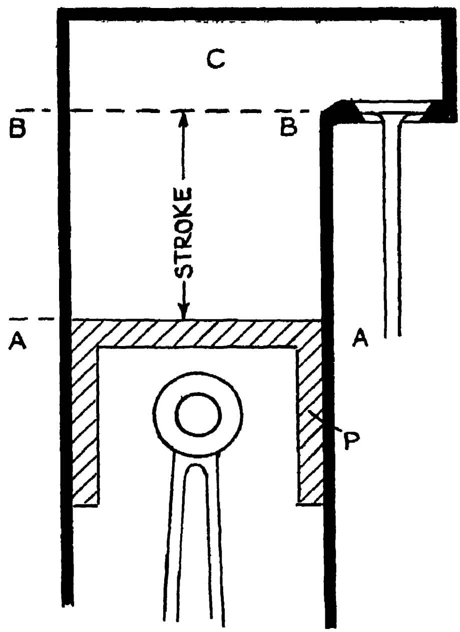


FIG 20 MEASURING THE COMPRESSION RATIO

be poured in until it just reached the cylinder head top. This was found to be 7 cub in. The bore of the engine was 3 in., and its stroke 4 in., giving a cubical capacity or stroke volume of $28\frac{1}{4}$ cub. in The compression ratio is therefore $\frac{28\frac{1}{4} + 7}{7} = 5$ (approx)

The oil method of measuring the compression ratio is quite a good one, provided an oil of medium thickness

is used, and no leakage occurs past the valves ; this will not happen if the oil is of medium grade.

In connection with multi-cylinder engines it is important that the compression ratio of all the cylinders be the same, otherwise the cylinders will develop unequal powers, and this will give rise to irregular running, or vibration.

THE COMPRESSION PRESSURE

Although it is possible to calculate the compression pressure in the cylinder of an internal combustion engine from its compression ratio, it is not always convenient to measure the ratio Many engineers are only concerned with the actual value of the compression pressure in each of the cylinders, in order to ascertain if there is any leakage of gases due to defective valves or valve seatings and worn pistons and cylinders.

It is possible to measure the actual pressure at the end of the compression stroke, using an ordinary pressure gauge of the Bourdon spring type, but in this case it is only the stationary pressure with the engine cold that can be measured ; it is impossible to measure the compression accurately when the engine is running, and one cylinder not firing

Apart from the use of rather complicated pressure-measuring instruments known as *indicators*, the compression, and also the explosion, pressure can be measured conveniently by means of the Okill pressure indicator (Fig. 21). In principle this consists of a spring-loaded piston, the other side of which is exposed to the combustion chamber pressure The spring pressure on the upper side of the piston can be varied by means of a micrometer screw adjustment that causes a cap to compress the spring until the spring pressure equals the cylinder pressure, this condition is shown by an indicating pointer provided for the purpose.

The force required to compress the spring being known, it is easy to ascertain the spring pressure of the piston for different degrees of compression of the spring, and therefore the pressure at any position. Referring

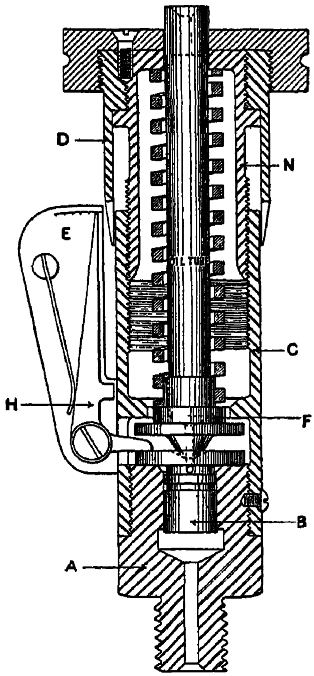


FIG 21 SECTIONAL VIEW OF OKILL PRESSURE INDICATOR

to Fig 22, there is a screwed cap that can be rotated by means of a milled head. As this is screwed down its movement is communicated by means of a train of three pinions to a simple counter, shown on the left

In using this instrument, it is screwed into the valve cap or cylinder head and the engine started, the counter reading being set at approximately the explosion pressure (250–350 lb. per sq. in.). The indicating hand

on the side will commence to pulsate if the explosion pressure is greater than the spring pressure As the latter is increased by screwing down the milled head, a point is reached when the pulsation just ceases At this point the spring pressure is just equal to the explosion pressure, and its value can be read off the indicator

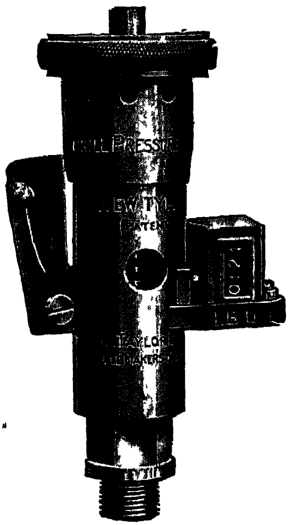


FIG 22 THE DIRECT READING OKILL PRESSURE GAUGE

For measuring the compression pressure under working conditions, the sparking plug of the cylinder to be measured is short-circuited so as to cut out the ignition, and whilst the engine is still hot and working on its other cylinders the compression pressure is measured in a similar manner to the explosion pressure If the engine is of the single-cylinder type it should be belt or electric motor driven whilst hot for the compression test.

It is important when making compression tests to have the *throttle* of the carburettor *fully open*, as the compression falls off in value progressively as the throttle is closed

The Okill indicator gives sufficiently accurate results for most practical purposes, and is therefore a useful instrument for the engineering test shop. It enables one to measure the compressions of the different cylinders and to compare their values with one another, and with the results obtained from other engines. In this way inequality, or loss of compression, can quickly be detected.

For more accurate work, since the instrument

becomes fairly hot, and the temperature of the spring alters its readings, it becomes necessary to water-jacket the cylinder It is also necessary to fit an electric contact in place of the vibrating pointer

This instrument can also be employed for measuring the explosion pressures with different fuels and carburettors, and to test the effect of different ignition lever settings.

MEASURING CYLINDER PRESSURES

It is often desirable to know exactly what is happening inside the cylinder of a petrol or other type of engine, and if we have some means of measuring the cylinder pressures at various parts of the piston stroke during a cycle of operations a very good clue to the internal behaviour is obtained.

There are now available special instruments, termed *indicators*, for obtaining graphical records of the pressure in a cylinder throughout its operation cycle

For slow-speed internal combustion engines, for example, gas and Diesel engines, the type of indicator shown in Fig 23 is quite satisfactory In this case a mechanism, known as the "straight line gear," is set into motion by the movement of a small spring-loaded piston in the indicator, one side of which communicates with the main cylinder of the engine , this piston then reproduces the pressures on the main piston A pencil point at one end of the mechanism records the vertical movements of the small piston, to an enlarged scale At the same time the vertical cylinder, on which the paper for the record is placed, is reciprocated to and fro by a suitable rocking mechanism operated from the engine This rocking movement corresponds with that of the main piston, but to a reduced scale

In this way a curve of cylinder pressures is obtained, from which the expert can at once adjudge the behaviour

of the engine. He can, for example, ascertain whether the ignition point is late or early, the mixture weak or strong, the compression good, etc. The Dobbie McInnes, Crosby, and Lunken are good indicators for this purpose For high-speed engines of the automobile and aircraft types a specially designed indicator, having very light moving parts and very small movements, is

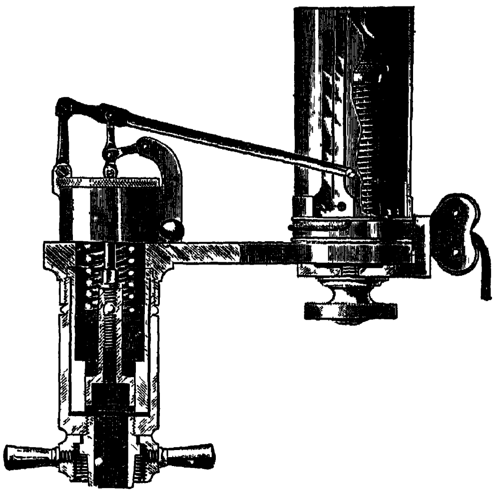


FIG 23 THE CROSBY INDICATOR FOR GAS, OIL, AND DIESEL ENGINES

employed In place of the relatively heavy mechanism and pencil (causing excessive friction at high speeds) a pair of mirrors, the movements of which are proportional to those of the pressure and piston's position in its stroke, is employed. A narrow beam of light is reflected from one mirror on to the other, and thence on to a ground glass screen, or if a permanent record is required, on to a photographic plate placed in a light-tight box. A powerful electric bulb or arc lamp supplies the illumination.

From the indicator diagrams obtained, the indicated horse-power, i.e the power developed within the cylinder itself, can be measured. Thus one has the required information concerning the efficiency of the

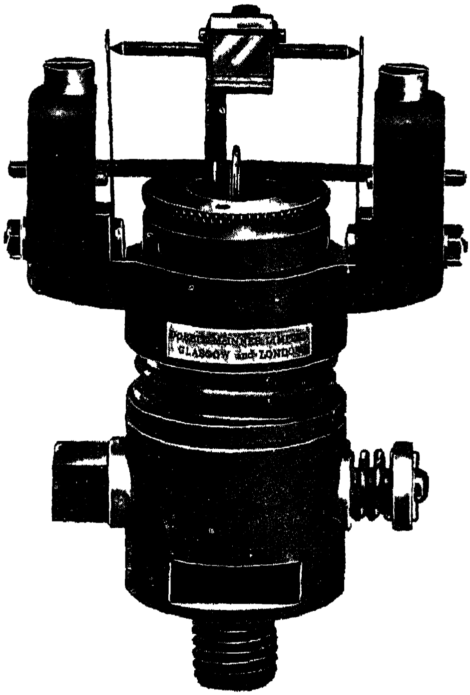


FIG 24 THE HOPKINSON HIGH-SPEED OPTICAL INDICATOR

The mirror shown is rocked about two axes proportionally to the pressure and piston position

cylinder itself, apart from many invaluable facts gleaned from the shapes of the diagrams themselves. Examples of satisfactory high-speed indicators on the market include the Hopkinson (Dobbie McInnes), Lunken (German), R A E. (Dobbie McInnes), Watson-Dalby, and the Midgeley (American).

MEASURING THE HORSE-POWER

One of the most important tests the engineer may have to carry out is that of the measurement of engine power. Knowledge of the horse-power delivered at different speeds is the only true indication of a motor-car or motor-cycle's road performance ; similarly, in the case of stationary internal combustion engines, this knowledge is necessary for specification and design purposes.

It is only by noting the power output of an engine under different conditions of running that the engine designer can introduce and test out improvements ; the development of an engine can only proceed as a result of such tests

From the repair engineering shop's point of view it is equally important to be able to ascertain the performance of an engine after it has been overhauled and adjusted. Most modern repair shops possess a test bay, or a separate test shop, fitted with the necessary apparatus for making horse-power and fuel consumption tests

In the process of tuning-up engines for road competition or racing purposes, the results of various adjustments, alterations to the valve cams, valve timing, ignition timing, piston and connecting rod design, oil pressure, and similar items, can at once be ascertained from horse-power and speed tests. Although the modern apparatus—known as power brakes—is somewhat elaborate and costly, there are several alternative simpler methods of measuring horse-power that can be used satisfactorily, more particularly in the case of smaller engines. We shall therefore describe the simpler, and one or two well-known makeshift, or workshop-rigged, methods of measuring the horse-power of an engine.

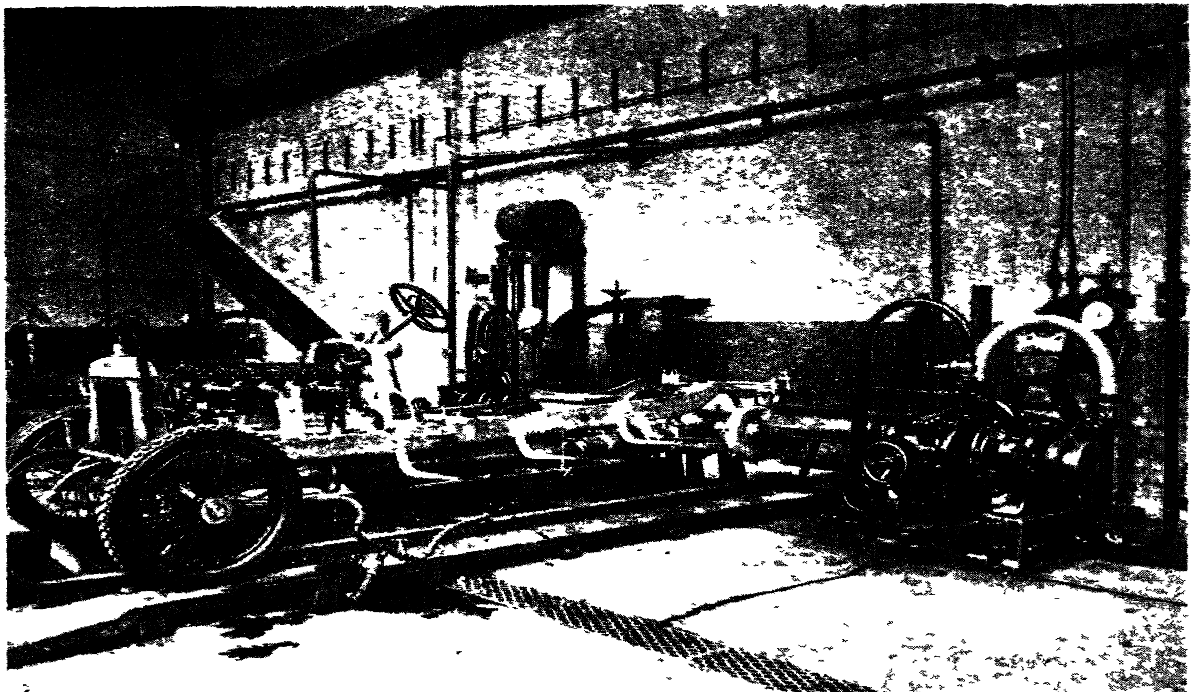


FIG 25 A DAIMLER CHASSIS ON THE TEST BED

The power delivered at the back axle is being measured by a pair of Froude hydraulic brakes

BRAKE HORSE-POWER

The term "horse-power" is usually taken to represent the amount of mechanical work done by exerting 33,000 ft.-lb. in 1 min. The fact that a period of time is specified indicates that power is really *the rate of doing work.* The standard horse-power is a convenient unit to employ, as it represents—or is supposed to represent—the average rate of working of an ordinary horse.

To express the meaning of horse-power in another way, if a machine could lift a weight of 33,000 lb through a vertical distance of 1 ft. in a minute, it would have exerted 1 h.p.

Now the horse-power that is generated or delivered by the exploding and expanding change in an internal combustion engine is always greater than that given by the crankshaft drive owing to the fact that power is used up or absorbed by the internal working parts of the engine, e.g. by piston friction, friction at the various bearings, and gear teeth. It is therefore necessary to distinguish between the original horse-power developed in the cylinder, and termed the *indicated horse-power*, (or i h p.), and that delivered at the crankshaft and available for power purposes; the latter horse-power is termed the *shaft*, or *brake horse-power* (or b.h p.). The term "brake" arises from the fact that the b.h.p is the power measured by the brake or dynamometer. The i.h.p. and b.h p. are related in a simple manner, as follows—

$$\text{i.h.p.} = \text{b h.p.} + \text{engine losses.}$$

Evidently, the lower the engine losses the higher will be the b.h.p., and therefore it is the aim of automobile designers and engineers to keep the losses at a minimum.

When comparing the performances of different designs of engines it is usual to speak of their mechanical

efficiencies, that is to say, the ratio of the b.h p.'s to i h.p 's. Thus, we have

$$\text{Mechanical efficiency} = \frac{\text{b.h p}}{\text{i.h p}}$$

The usual value of the mechanical efficiency in a modern petrol engine is about 85 to 90 per cent ; it tends to become less at the higher speeds. A mechanical efficiency of 90 per cent means that 10 per cent of the engine's power (i h.p) is absorbed by the engine itself , an 85 per cent mechanical efficiency indicates 15 per cent engine losses, and so on

From the above it will be evident that we have a satisfactory method of comparing the performances of various types of engines.

SIMPLE TYPES OF POWER BRAKE

To measure the horse-power of an engine it is usual to fit some type of power-absorbing device or brake to the engine's shaft, and by applying well-known principles of turning-moment (or torque) and speed to certain measurements made with the brake, it is possible to work out the horse-power The simplest type of power brake used for engine test is the fan brake, consisting of a number of arms—usually two or four—clamped to the outside of the crankshaft, each arm carrying a flat paddle or blade These blades, when rotated quickly, paddle or churn the air, thus offering a resistance to the motion of the crankshaft

The Walker fan brake illustrated has two arms and two blades. The arms are so arranged that they can be clamped to the protruding portion of the crankshaft outside the crankcase. The blades can be bolted at different radii along the arms The larger the blades and the greater the radii at which they are bolted, the more horse-power they will absorb

The makers supply tabulated particulars showing the horse-power absorbed at different speeds, and for different sizes of blades and radii. One can thus select the most probable size of blade and, having about fifteen different radii to choose from, can obtain different values of horse-power absorbed. The makers also give a chart showing the actual brake horse-power corresponding to each radius and size of blade over a wide range of speeds.

In making a fan brake test, therefore, one has only to ascertain, by trial, the blade and radius to absorb

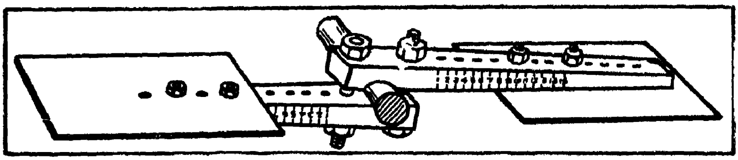


FIG 26 THE WALKER FAN, OR AIR, BRAKE

the engine's horse-power at a given speed, making a note of this speed The brake horse-power corresponding to this speed is then read off the maker's curves, or extracted from corresponding tables.

The Walker fan brake therefore requires the use of a speed-measuring instrument only. This brake has been widely used for motor-cycle and car engine tests, as well as for aircraft engines In the absence of a proper power brake, it is possible to rig up a makeshift expedient that will give fairly accurate results There are two types of brake, namely, the Prony and the Rope brake, that can be used in this manner

The Prony brake employs friction material, such as wood, fibre, or Ferodo fabric, to absorb the power of the engine, and a weighted arm or lever to measure the power.

Fig. 27 illustrates a typical Prony brake. In order to use this brake a flywheel or pulley *W* is secured

centrally to the crankshaft of the engine to be tested, and two sets of wooden blocks F are held against the flywheel or pulley W, by means of metal straps A and B and bolts and nuts One of the bolts has a spring-loaded nut S The upper strap A is extended to carry a counterbalance weight C at one end and a lever arm and hook at the other The hook carries the weights W.

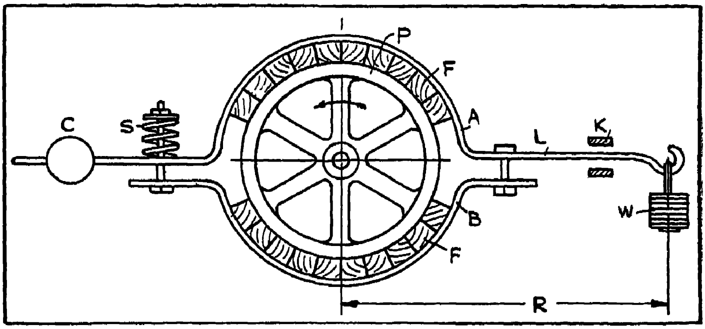


FIG 27 A USEFUL WORKSHOP METHOD OF MEASURING BRAKE HORSE-POWER
Using the Prony friction brake

A pair of stops K is provided to limit the movement of the lever arm L

When in use the frictional resistance to rotation of the blocks bearing on the pulley W is such that the complete brake tends to rotate in the direction shown by the arrow This tendency is counteracted by weights W on the scale pan, until the lever L just floats between the stops K

When thus balanced, the frictional torque on the pulley is equal to the engine torque The former torque is also equal to the torque $W \times R$, where R is the distance of the weight from the centre line through the pulley.

The horse-power can then be calculated from the formula .

$$\text{b h p} = k \times W \times R \times N$$

where k is a constant having the value $\frac{1}{5250}$, and N is the engine speed in rev. per min.

If we make the radius $R = 5{\cdot}25$ ft, the above relation becomes $\frac{W \times N}{1000}$

Thus, if during a certain brake test a weight of 25 lb is required at a speed of 1500 r.p.m., the horse-power at this speed is given by

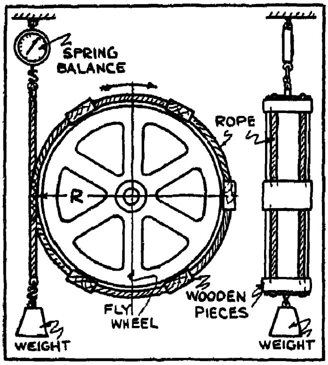


FIG 28. THE ROPE BRAKE METHOD

$$\text{b.h p} = \frac{25 \times 1500}{1000} = 37\tfrac{1}{2}$$

Tests have shown that with beech blocks it is possible to absorb a little over 100 h p with a weight of 100 lb at a lever arm of 6 ft., at 1000 r p.m.

One disadvantage of the Prony brake is that it can only be used for the larger sizes of engine, i.e. over 20 h.p., by having water-cooled flywheel rims (Fig 29), owing to the heat generated by the friction of the blocks

An improvement on the design illustrated in Fig 27 is the type in which the friction blocks are attached to a flexible steel band, this prevents any "snatching," and damps out oscillation.

Another simple type of brake that can readily be rigged up in the test shop is that known as the *Rope Brake* (Fig. 28). In this case a number of friction blocks are secured to a rope passing around the rim of the engine's flywheel, or a suitable pulley fitted to the camshaft One end of the rope carries a weight W, whilst the other end is attached to the hook of a spring balance.

When the flywheel rotates in the direction of the arrow it tends to lift the weight W, the pull of the spring opposes the weight, so that there is a total pull of ($W-$ spring balance pull P) acting at the radius R, measured to the centre of the rope. The product $R \times (W - P)$ is equal to the torque of the engine when

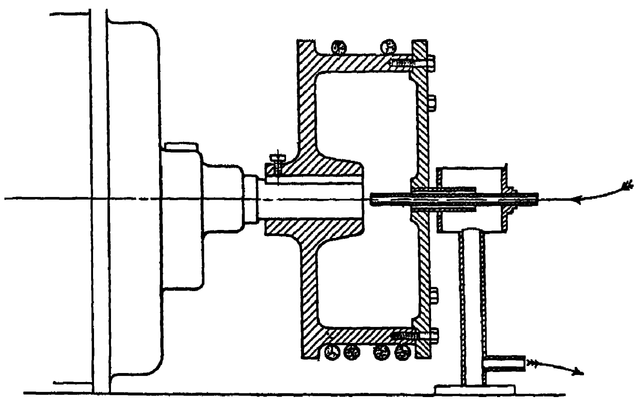


FIG 29 SHOWING METHOD OF WATER-COOLING THE BRAKE DRUM OF A ROPE BRAKE TESTING ARRANGEMENT

the latter is balanced by adjusting the weight W, and the engine is running smoothly under its load

The brake horse-power is then given by b h.p. $= k \times (W - P) \times R \times N$ where N is the speed in r.p.m and, as before, $k = \dfrac{1}{5250}$

This is a simple type of brake to construct, and it can be used with satisfactory results for engines of small and moderate powers It should be mentioned that in the case of the Prony brake, previously described, the weight W may be replaced by a spring balance and tensioning screw, by adjusting the latter any value of load can be obtained, this load being read off the spring balance scale

BRAKES FOR HEAVY LOADS

The power absorption brakes, previously described, are mostly suitable for engines of relatively small power. It frequently happens, however, that larger powers have to be dealt with, so that it becomes necessary to use another type of brake, or dynamometer The best methods of absorbing and measuring the higher powers of internal combustion engines are: (1) the electrical, and (2) the hydraulic ones

In the electrical method the engine is coupled to a dynamo, the latter absorbing the power of the engine. It is usual to fit a variable resistance field, and also to arrange the brush and field connections so that the dynamo can be quickly converted—by the simple process of throwing over a switch—into a motor. Used as a motor it can run the engine for "bedding-in" the bearings after overhaul, or when the engine is new, and can also be used for starting the engine. This is a very convenient works test arrangement, and is much used

Another method is to mount the framing or casing of the motor on knife-edges, and to provide it with a lever arm on which weights can be hung The magnetic drag of the armature tends to pull the casing around with it, but this tendency is counteracted by means of the weighted lever arm. The engine torque is then equal to the product of the weight and its distance from the centre of dynamo shaft, and a similar formula to that of the Prony brake is used for estimating the brake horse-power.

The Sprague electric dynamometer (Fig. 30) works on this principle. The hydraulic brake consists briefly of a number of paddles or cup-shaped scoops, immersed in a casing kept full of water The paddles or scoops are attached to the engine crankshaft, and are rotated in the water. The latter offers a big resistance to the motion of the paddles, or scoops, the engine's power

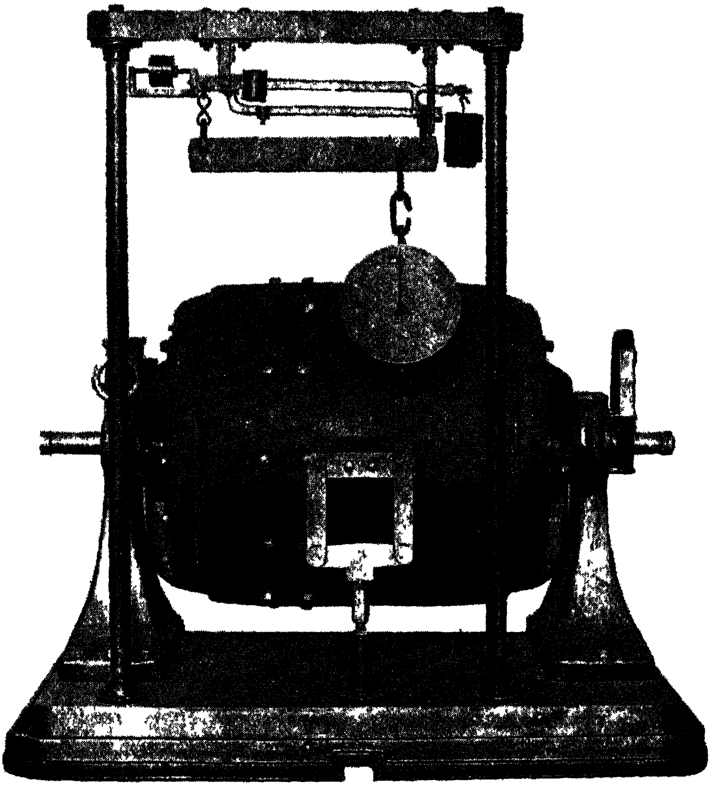


FIG 30. THE SPRAGUE ELECTRICAL DYNAMOMETER
Used for absorbing and measuring power

being absorbed in the process The water, in being swirled about and churned, becomes heated, and in the better types of hydraulic brake a supply of cold water is kept running through the casing

The hydraulic brake may be regarded as a fan brake acting in water, instead of air

Just as in the case of the electric brake, previously described, the casing experiences an equal torque, or tendency to turn to engine torque, so in the hydraulic brake, the casing—which can swing around the paddle shaft—can turn, its turning moment being measured by means of a lever arm and loaded scale-pan or spring balance.

In the case of the Froude water brake, there is a pair of paddles with pockets, or scoops, that rotate with the shaft, whilst the casing contains similar pockets, so that the maximum amount of churning —or resistance—is experienced The load on the brake can be varied by means of a sluice plate worked with a hand wheel. This sluice plate on being screwed down covers up part of the casing pockets, thus reducing the churning action and, therefore, the load. Water enters the machine continually through a water inlet pipe, and passes to both sides of the casing.

The Froude brake described is widely used in connection with the testing of petrol, gas, and oil engines It is made in a wide range of sizes for absorbing and measuring the horse-power outputs of small petrol engines (of 10 to 20 b h p.) up to large Diesel engine installations of 30,000 b.h p , running at 80 to 150 r.p.m.

Water-cooled aircraft engines can also be tested with a special air brake dynamometer known as the Heenan-Fell; it works on the same principle as a fan brake, but is more elaborate, and is provided with many refinements.

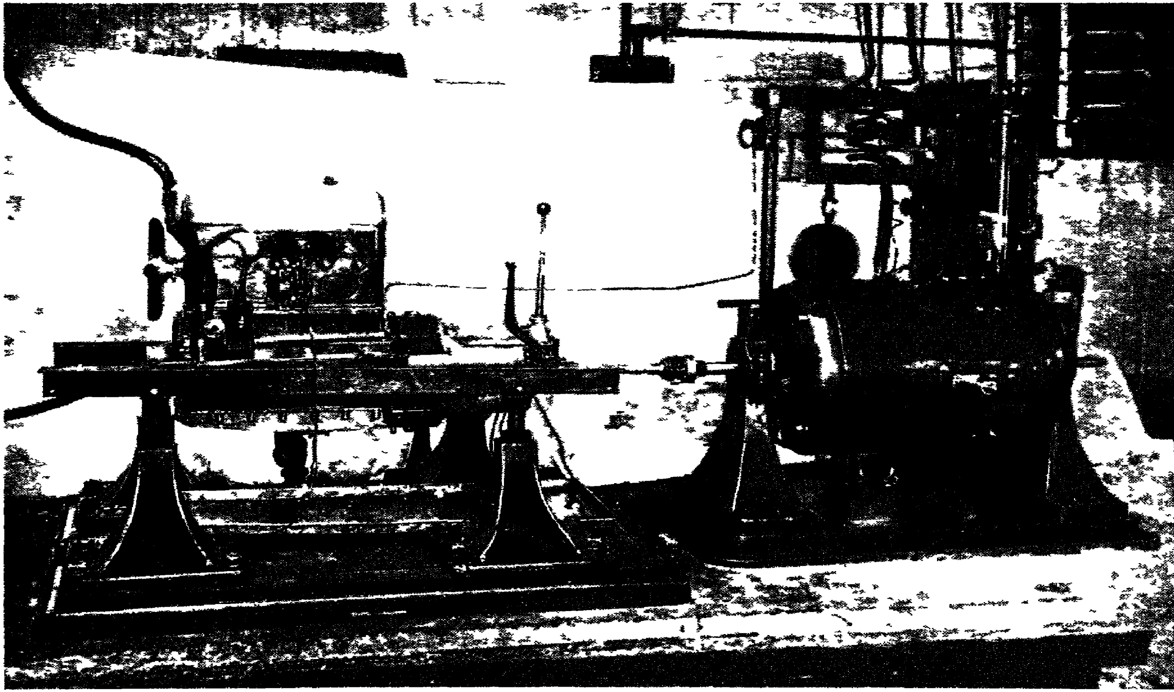


FIG 31 SHOWING THE SPRAGUE ELECTRIC DYNAMOMETER COUPLED TO A MOTOR-CAR ENGINE FOR B H P TESTS

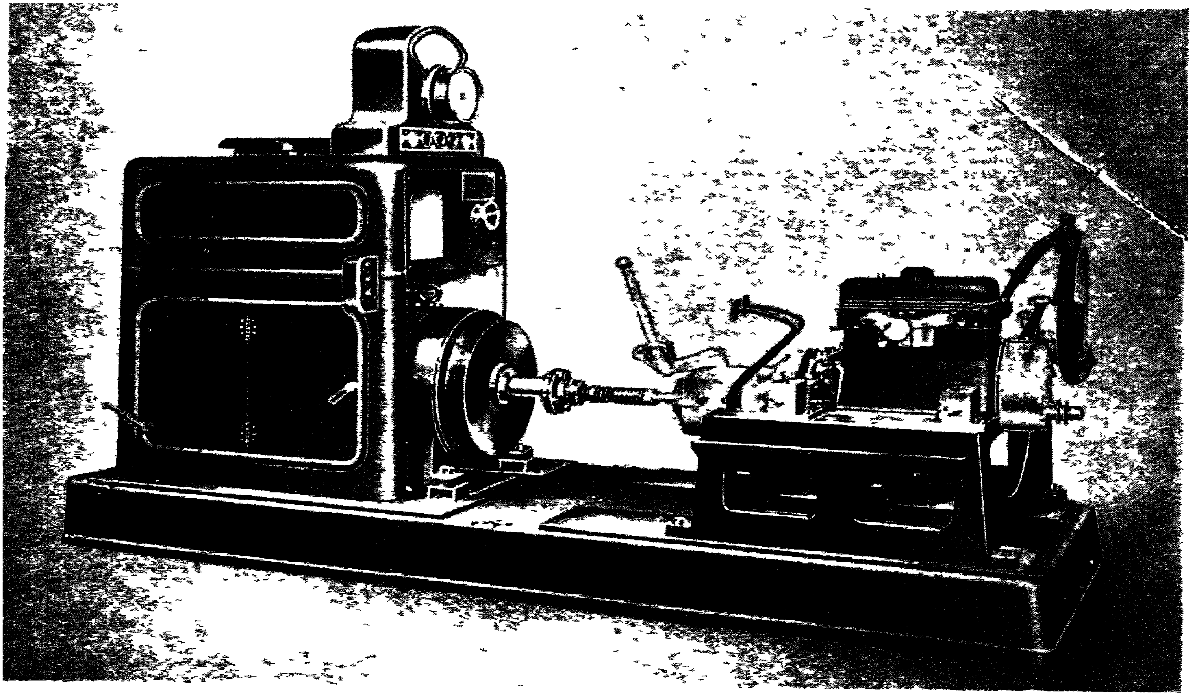


FIG 32 THE HEENAN-HIGHFIELD ELECTRIC DYNAMOMETER
Used for testing and running-in Morris and other car engines

ON KEEPING TEST RECORDS

When making tests of engines it is necessary to make a note of all the available data, and of the test conditions, on properly prepared test charts or logs.

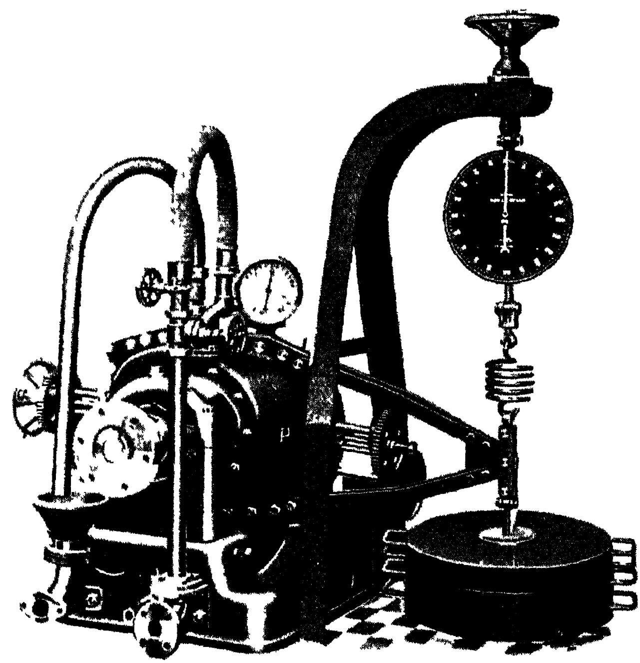


FIG 33. THE HEENAN-FROUDE HYDRAULIC BRAKE
For brake horse-power tests of internal combustion engines of all types

These should contain full particulars of the engine, including its make, number, dimensions (i e bore and stroke), compression ratio, number of cylinders, fuel used, etc.

The following is a typical test chart suitable for horse-power and speed tests.

TEST LOG SHEET

No of Test______

Make of Engine ______________________	Fuel Used ______________
No of Cylinders ______________________	Density ______________
Bore__________mm __________in	Temperature of Air ________
Stroke__________mm __________in	Barometer Reading ________
Cubical Capacity ________________c.c.	Observer ______________
Compression Ratio ______________________	Date ______________

Run No	Speed Counter Reading	Time				Tachometer Readings	Torque Arm Load (lb)	Water Temp.	
		Start		Finish				Inlet	Outlet
		M	S	M	S	Rev per Min		Deg F	Deg F

Other additional data that can be usefully added are the oil consumption and fuel consumption

It is best to have proper test sheets printed, so that they can be mounted on a board for noting down the various readings. They can afterwards be filed in readiness for the results to be worked out from them. The latter should be entered in a special test records book. A space should be left for the observer's remarks on miscellaneous items noted during the tests. The carburation or mixture setting and the ignition advance lever position should always be noted during tests.

Any alterations made prior to, or during, the tests should be noted down, and a note made of adjustments, stops, and other items.

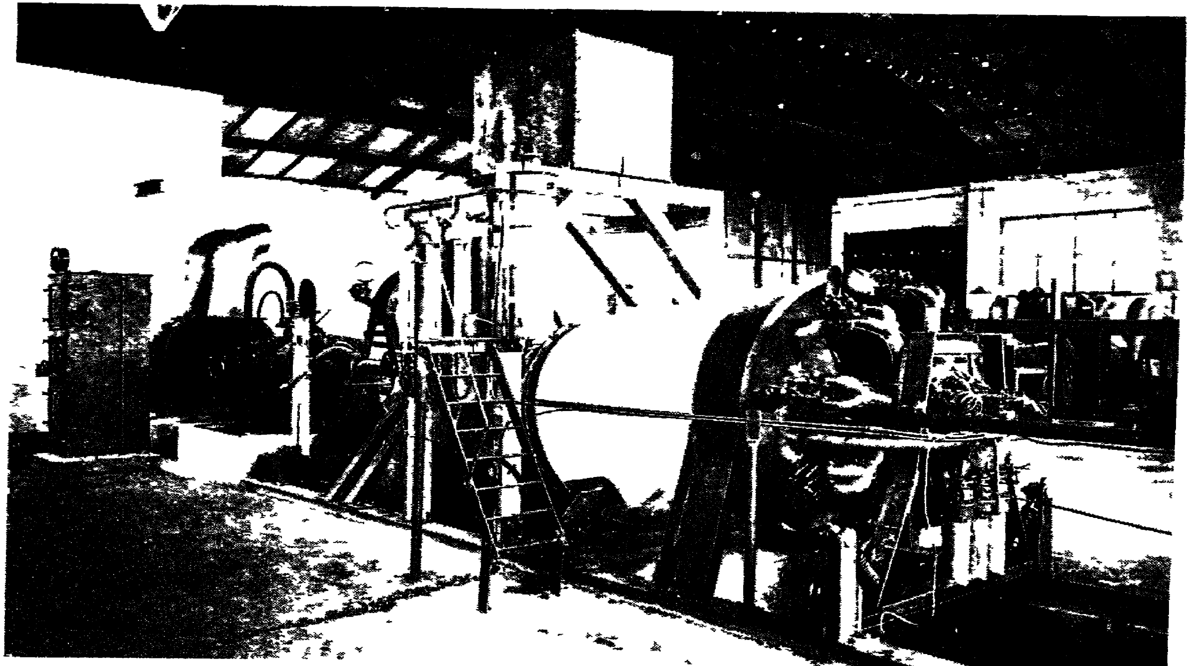


FIG 34 THE AIR-COOLED BRISTOL JUPITER ENGINE ON THE TEST BED

A Froude brake measures the power, and a large cooling duct keeps the engine at its proper working temperature

NOTES ON TEST PROCEDURE

Before making any tests upon an engine or its components the exact object of the test should be kept in mind, in order that the test conditions may be arranged accordingly. There is a very important point concerning test procedure that is frequently overlooked by test engineers, and in consequence the results obtained are rendered practically worthless This point refers to the maintenance of *constant test conditions*, in order that only one variable quantity be tested at a time. There are several variable quantities in internal combustion engines, including the mixture strength (i e the proportion of air to fuel), the throttle opening, ignition timing, engine speed, water temperature, load on engine, oil temperature, etc When making a test of any one of these factors see that the others are kept unaltered in value, the test chart previously mentioned has been devised for this purpose If, however, a maximum horse-power speed test is being made, then for each speed of test it will be permissible to alter the ignition timing and mixture strength, in order to obtain the highest power reading

The engine itself should be in thoroughly sound working condition before the test. For an important test it is usual to strip an engine and overhaul or adjust it beforehand In the case of overhauled or new engines, these must be properly "run in" for a period of 10 to 15 hours, at least

Before any tests are made on an engine it should be given a preliminary run of half an hour or so, then stopped, and the tappet clearances, oil level, sparking plug points, etc, examined. The valve clearances should always be checked after the running-in test, and all nuts likely to have slacked a little gone over with a spanner. The detachable head and the holding-down nuts should be thus checked.

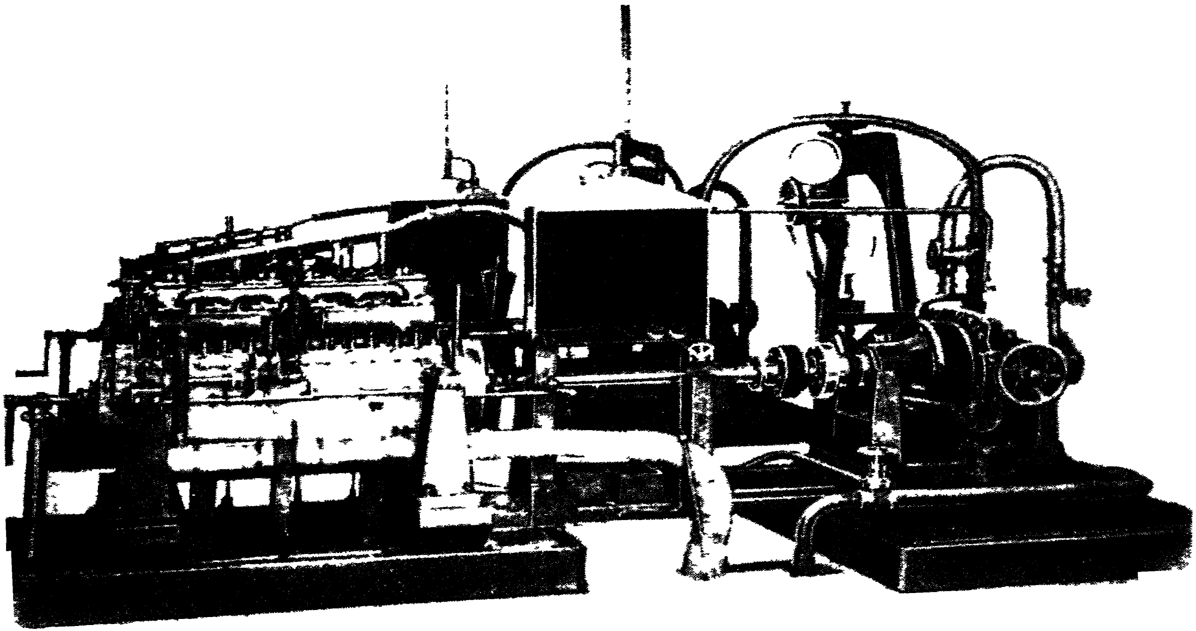


Fig 35 A Pair of Rolls-Royce Car Engines under b.h.p. Tests, with Froude Hydraulic Br

It should be noted that car radiators are u

When arranging the engine on the test bed, it is advisable to run the exhaust to an underground expansion chamber, through a flexible metal pipe of ample section. Most test works have proper concrete or pipe conduits for leading the exhaust gases away; these, being of ample size, also act as silencers, the cooled gases being exhausted outside the test shop into the air

When making tests on automobile engines, the cooling water can be kept cool either by means of a large galvanized tank having a cold water supply and overflow pipe, or by means of a fan-cooled car radiator It is usual to have one or two power-driven fans near the engine to deliver a cooling draught, to emulate road conditions. Fig. 35 shows a typical radiator method of cooling

Air-cooled engines should be tested in the slip-stream of a fan or propeller under similar conditions of air speed and temperature as experienced in practice (Fig. 34)

When tuning an engine for maximum power, it is necessary to use a mixture of air and petrol or other fuel rather richer in fuel than that required for perfect combustion, this gives more power Thus, if the engine is running on petrol, the perfect combustion mixture consists of 15 parts air to 1 part petrol, whereas that for maximum power consists of 13 parts air to 1 part petrol The ignition advance should be sufficient to give the greatest speed under the given load conditions.

When making horse-power tests it is advisable to make tests of the fuel consumption at the same time, this gives a check upon engine efficiency and mixture strength.

SECTION XXXV

STEAM ENGINE AND PUMP FITTING AND ERECTING

BY

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SECTION XXXV

STEAM ENGINE AND PUMP FITTING AND ERECTING

STEAM ENGINES

THE history of the steam engine is distinguished by the brilliant achievements of British inventors and craftsmen. The names of Newcomen, Watt, Trevithick, Stephenson, and Willans are familiar to engineers all over the world, and the original patent covering the Uniflow principle was granted to an Englishman in 1885. At all stages developments on the technical side have been accompanied by improved technique in the workshop, and the old-time engine fitter was a craftsman of the highest order It is true that modern machine tools and materials have eliminated much of the skilled fitting of olden days, but it is still a fact that the successful operation of an installation depends to a great extent upon the skill of the fitter and erector. Good design, accurate machining, and excellent materials are all essential to economical and quiet working, but, in spite of these, many a good engine has been spoiled by careless fitting of valves and bearings, or by inaccuracies of alignment Thus, it is the common experience of engine builders that engines built from the same designs and from similar materials frequently exhibit marked differences in their behaviour under actual working conditions

TYPES OF STEAM ENGINES

The methods adopted during the fitting and erection of any particular installation depend, in a large measure,

upon the type and arrangement of the machine The following is a summary of the principal types of steam engines found in industrial practice, and the

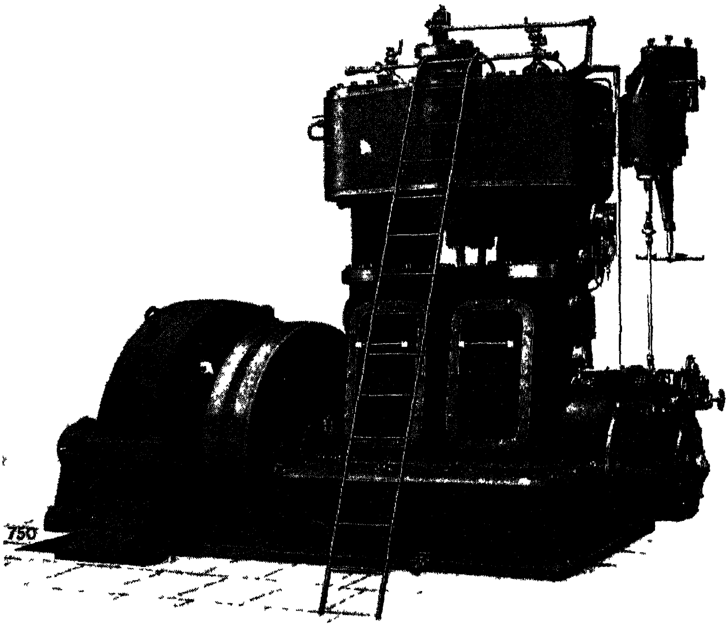


FIG 1 BELLISS HIGH-SPEED ENGINE

illustrations help to make clear the marked differences in the designs of various makers

VERTICAL ENGINES

(*a*) Totally enclosed engines of the high-speed (quick revolution) type, with piston slide valves and forced lubrication Fig 1 is from a photograph of an engine of this type built by Messrs Belliss and Morcom.

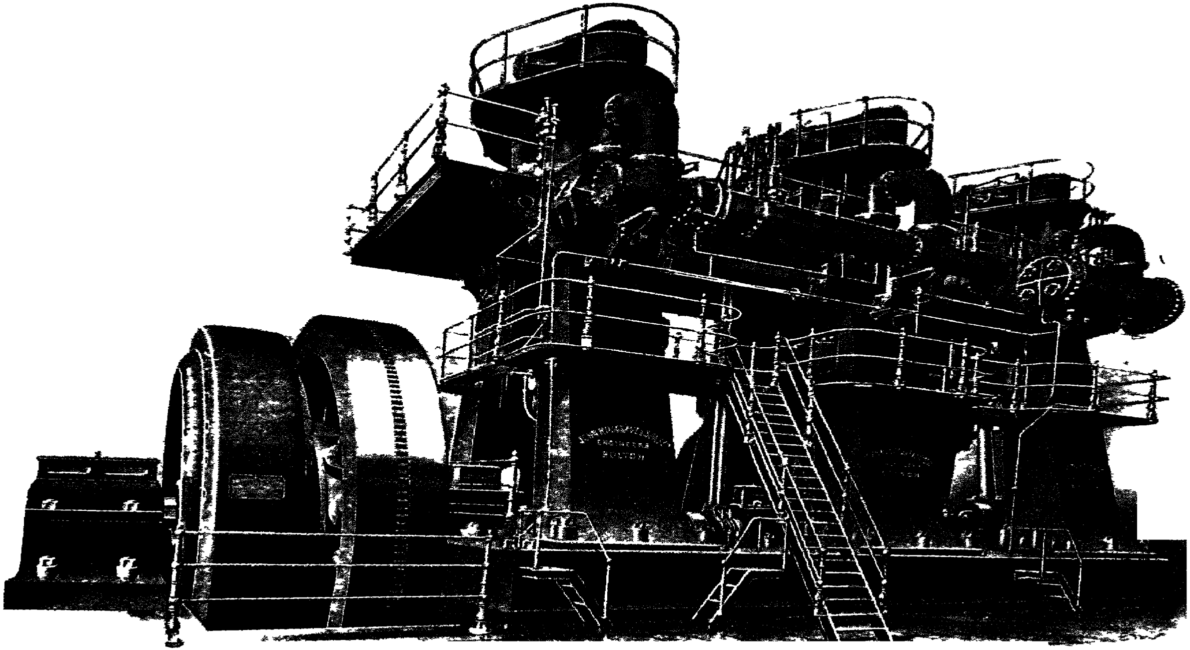


FIG. 2. 5000 I.H.P. COMPOUND ENGINE

Such engines are built with single or twin H P cylinders and also with compound or triple expansion cylinders They are designed to work condensing, against a back pressure or with intermediate steam extraction for process work

(*b*) Open type slow-speed engines with piston or "D" slide valves, Corliss or drop valves with trip gears with single or twin H.P. cylinders, or compound, triple or quadruple expansion cylinders. An example of a large vertical engine of this type is shown in Fig. 2.

HORIZONTAL ENGINES

(*c*) Totally enclosed, medium speed, single-cylinder, Uniflow engines, with two seating or piston type drop valves, central exhaust ports, and forced lubrication, designed to work condensing. A complete installation of this type is shown in Fig. 3

(*d*) Totally enclosed, medium speed, single-cylinder, back-pressure engines, with two admission and two exhaust drop valves; designed to exhaust against back pressures for process purposes.

Fig. 4 shows an engine of this type during the course of erection in the shop

(*e*) Totally enclosed, medium speed, compound engines with four-valve H P. cylinders, and Uniflow type L P. cylinders; designed for intermediate steam extraction, and with condensing plant for L.P exhaust steam The cylinders may be arranged in tandem fashion as in the example by Messrs. Galloways, Ltd., of Manchester (Fig 5), or in cross-compound fashion

(*f*) Open type, medium speed engines with single, twin, compound, triple, or quadruple expansion cylinders, and with slide, Corliss, or drop valves. Fig. 6 illustrates a tandem-compound, Corliss valve engine of this type in the erecting shop of the makers—Messrs.

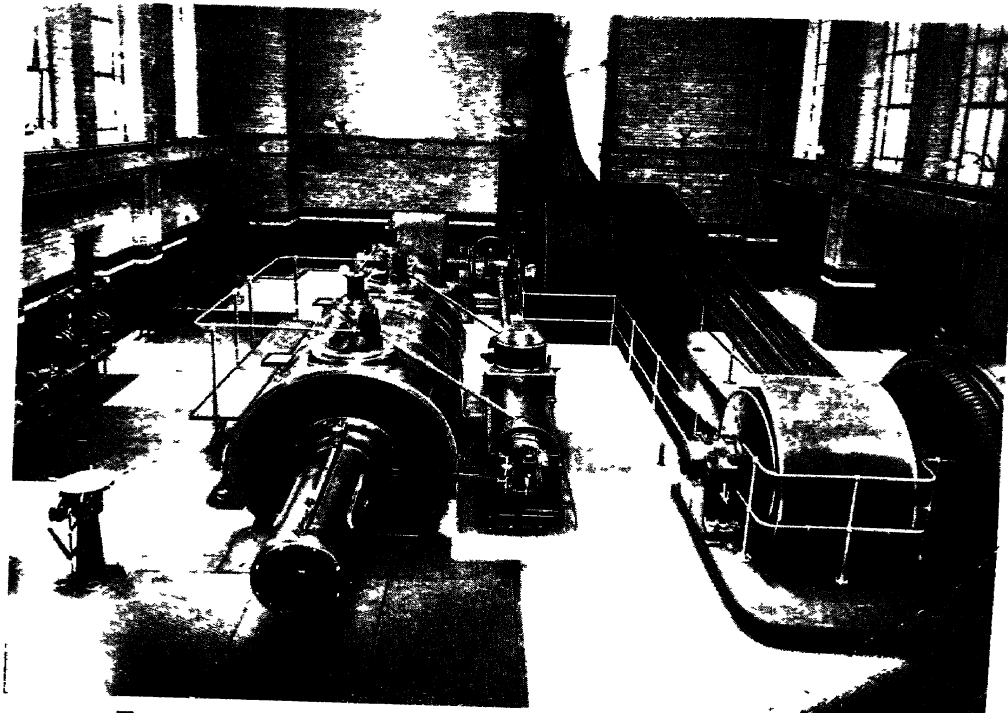


Fig 3 1620 I.H.P Uniflow Engine, Driving Cotton Mill

Hick, Hargreaves & Co, Ltd, Bolton This engine was supplied for driving a rolling mill.

Quadruple expansion engines are rarely built nowadays, and the open types are not in great demand, except in small sizes, or for the purpose of marine propulsion The cylinder arrangements of the horizontal types are shown diagrammatically in Fig 7, and the manner in which the power may be transmitted from a single-crank horizontal engine is illustrated in Fig 8.

Condensers may be of the jet type with centrifugal extraction pumps (as in Fig. 9), and steam-ejector air pumps (shown close to the wall in Fig. 3), or with reciprocating air pumps driven through ropes or link motion from the tail rod or crankshaft. Surface condensers, with reciprocating air pumps and centrifugal (or reciprocating) circulating pumps, may likewise be fitted, or the air pumps may be of the steam-ejector type, with centrifugal condensate and circulating pumps

ORGANIZATION OF WORKSHOPS

The methods adopted in the workshops vary in accordance with the capacity of the works and the size of the machinery turned out. In small shops, building small engines, the same men often perform the fitting *and* erection of the parts, and, in some cases, the machining too. In large shops, separate departments are arranged for pattern-making, foundry work, machining, fitting, and erection, respectively Some of the departments are, in turn, subdivided into sections, such as those devoted to marking-off, fitting of valve gear, small parts, etc

PROGRESS OF MANUFACTURE

The castings, after being dressed, cleaned and inspected, pass to the marking tables, where they are

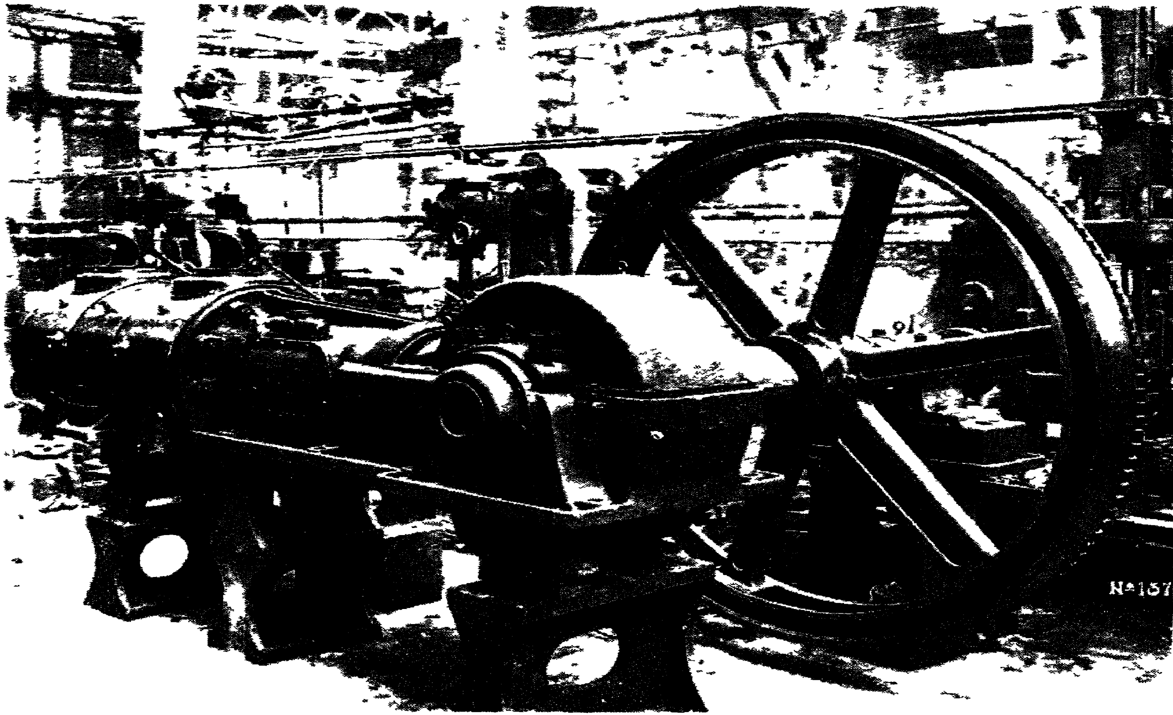


Fig 4 150 I.H P. Back Pressure Engine in Erecting Shop

tried up and marked off for the initial machining operations. Machining and marking-off then alternate, until the part is completely machined to the dimensions and limits shown on the drawings Much time and labour may be saved by the proper organization of this work. Care should be taken to ensure that as many operations as possible are performed with one setting of the machine, and that the transport between one machine and another is reduced to a minimum Progress should be so ordered that the whole of the parts required during erection are ready when they are required, and that the equipment of the factory is kept as fully employed as the state of the order book allows. Automatic lathes should be employed whereever possible for the manufacture of pins, bolts, and other small parts After leaving the machine shop the parts are inspected and gauged, and items such as cylinders and jackets tested by hydraulic pressure.

Frequently it is specified that certain parts, e g crankshafts, should be inspected by the surveyors of insurance companies at various stages of manufacture, so that they may be certified free from flaws or errors in alignment.

Similarly, individual parts may require inspection by the representatives of the purchaser prior to painting, caulking, or any similar process Parts which fail to pass the tests and inspection are, of course, rejected, and the remainder pass to the fitting departments In these departments holes are tapped, surfaces filed and scraped, sharp corners removed, nuts, pins and keys fitted, and such other operations completed as are not possible in the machine shops. Small detail assemblies are also made in the fitting shops, e.g. the fitting and assembly of valves, crossheads, etc. A good illustration of this work is given by Fig. 10, which is from a photograph taken in the works of

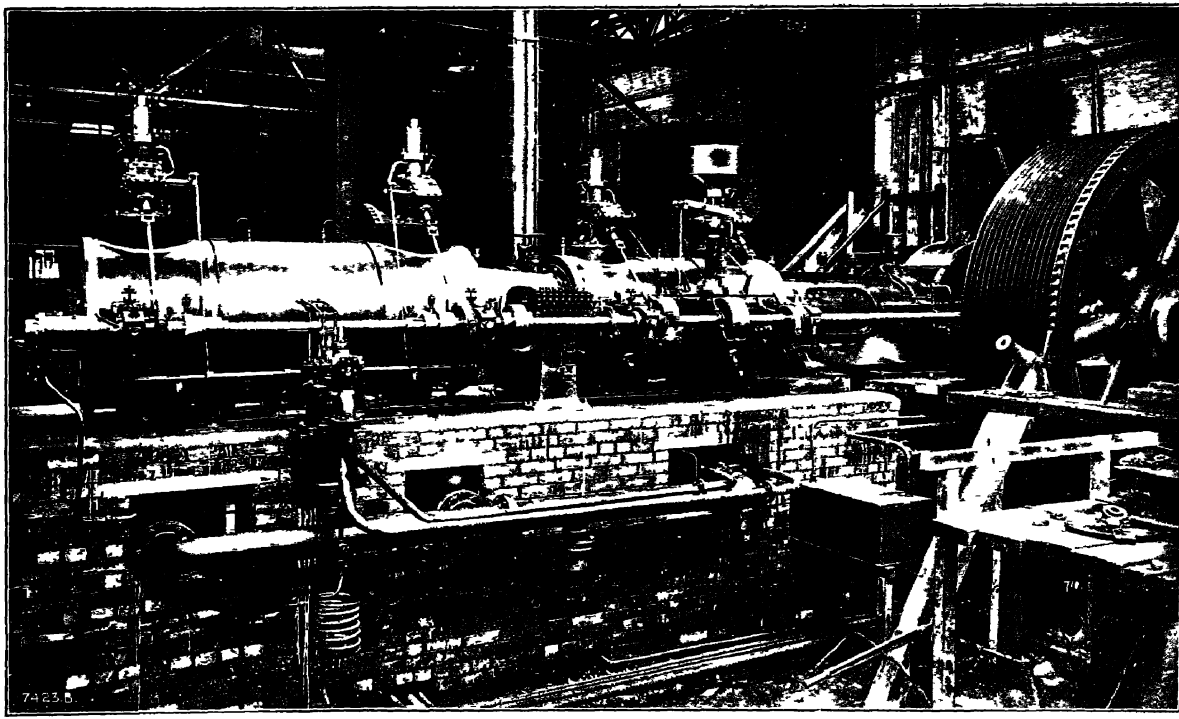


FIG. 5. 275–350 H P. "GALLOWAY" STEAM EXTRACTION ENGINE IN COURSE OF ERECTION

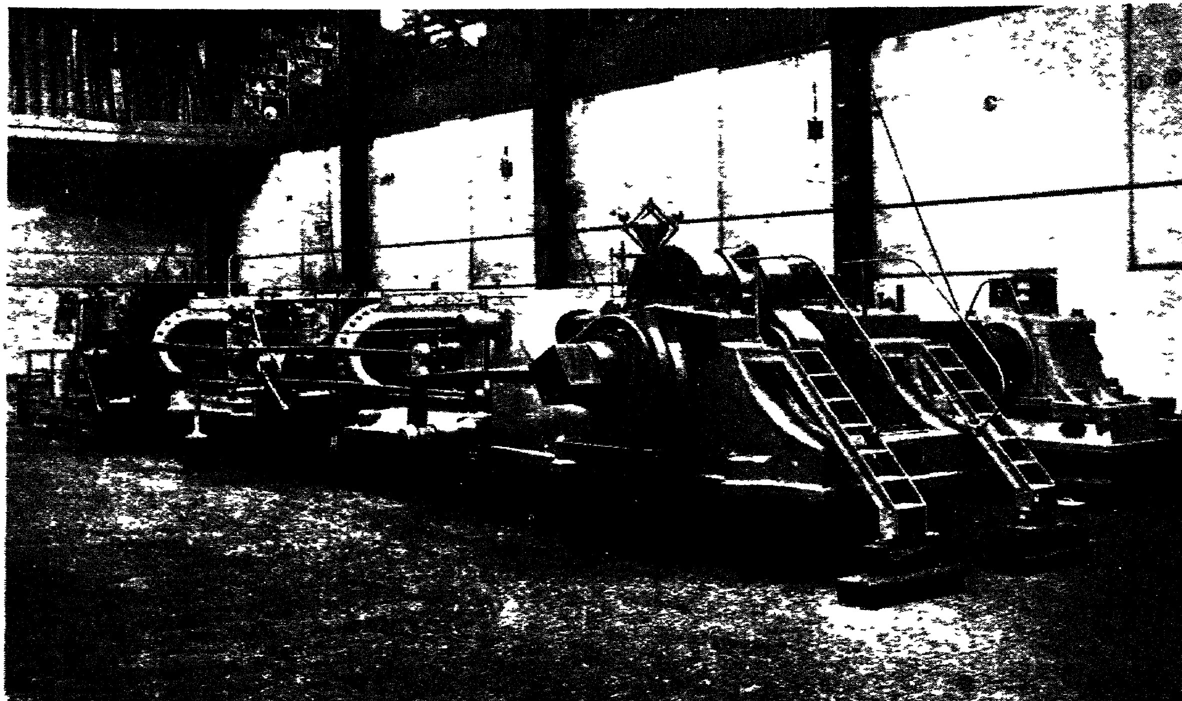


FIG 6 780 I.H P HORIZONTAL COMPOUND ENGINE

Messrs Belliss and Morcom, the well-known builders of high-speed steam-engines Modern methods are designed to transfer, from the fitter to the machine, much of the skilled fitting necessary in former days. It is essential, however, that the fitter should appreciate the importance of good workmanship. Screw threads, keys and pins, should be carefully fitted, especially in the case of important parts, such as connecting rod bolts and main bearing studs. All operations should be performed with an intelligent anticipation of the functions which the parts will be called upon to perform, and the stresses to which they will be subject Scraped bearings and joints should be prepared with the assistance of the minimum amount of marking, and the skilled fitter should endeavour to acquire facility in operations such as tempering, lining of bearings, and pipe bending. His practical knowledge cannot, in fact, cover too wide a field, as if, ultimately, he is given charge of outside erections he will not be able to call upon the assistance of allied departments

BEDS FOR ERECTION

When the parts are finally completed they are passed to the erecting shop for preliminary erection in the shops Small engines—and engines supported on bed plates, which constitute the lowest portions of the machines—are often erected on machined erecting beds, where little levelling is necessary Large horizontal engines, with valves, pipes and receivers projecting below the level of the floor, are not, however, often erected in this manner In such cases, the engine is generally erected on some suitable portion of the erecting shop floor. In Fig. 4 the floor is of concrete, with cast iron supports to raise the engine to the height necessary for the accommodation of the lower parts. The floor in Fig. 6 is of wooden setts, with baulks of

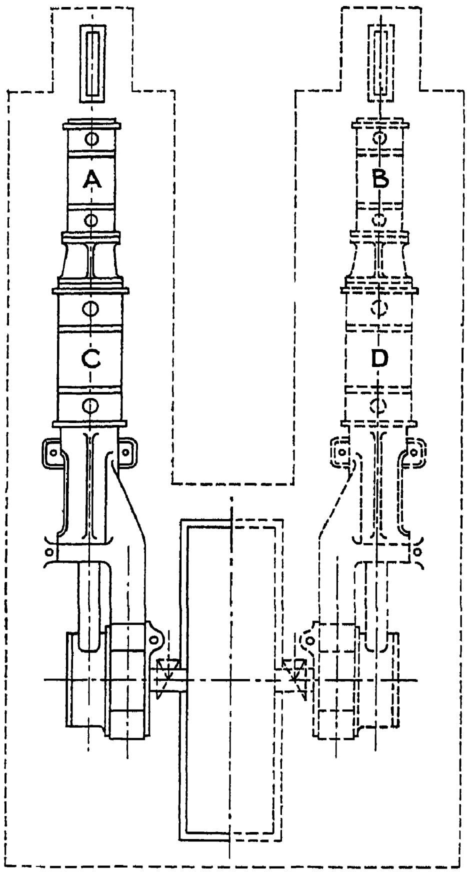


FIG 7 ARRANGEMENT OF CYLINDERS FOR HORIZONTAL ENGINES

SIMPLE EXPANSION	COMPOUND EXPANSION	
1 Cylinder H P —*C*	Cross-compound cylinders .	H.P —*C* L P —*D*
2 Cylinders H P 's—*C* and *D*	Tandem-compound cylinders .	H P —*A* L P—*C*
	Twin-tandem compound cylinders	H P.'s—*A* and *B*
	Twin-tandem compound cylinders	L P 's—*C* and *D*

TRIPLE EXPANSION

3 Cylinders .	H P —*A*
3 Cylinders .	L P —*C*
3 Cylinders	L P.—*D*
4 Cylinders	H P —*A*
4 Cylinders .	L.P.—*B*
4 Cylinders	L P 's—*C* and *D*

timber supporting the engine at a convenient height Wooden setts, with cast iron blocks, are also shown in Figs. 11 and 12, which give further views of the erecting shops of Messrs Belliss and Morcom. Ample handling facilities are features in these workshops. The illustrations show various operations in progress

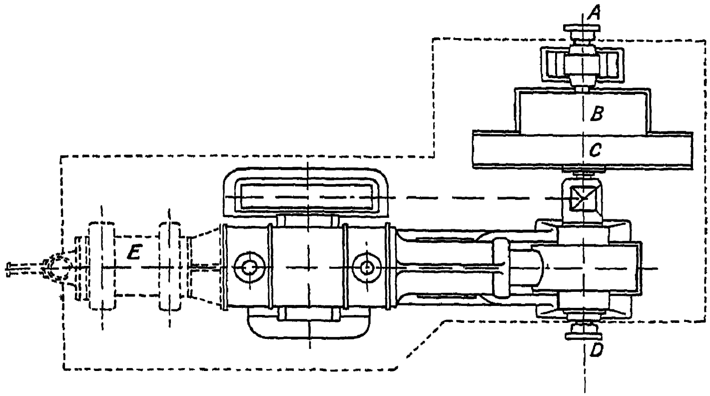


FIG 8 DIAGRAMMATIC OUTLINE ILLUSTRATING ENGINE DRIVES

Direct Drive Through coupling at *A*, or to alternator at *B*, with exciter at *A*

Rope Drive From rope flywheel at *C*, or rope pulley at *B*, alongside plain flywheel at *C*

Belt Drive From plain flywheel at *C*, or belt pulley at *B*, alongside plain flywheel

Combined Drive, Through couplings *A* and *D*, with rope or belt drive from *C* or *B*

Drive through Tail Rod Direct to pump or air cylinder at *E*

and a number of engines in different stages of completion is visible They also exemplify the difference between the arrangements in the case of high-speed engines—where numbers of standard machines are erected together on a general erecting bed—and those for slow-speed machines, where a general bed is hardly practicable, and portions of the erecting shop floor are selected to suit particular cases

In the latter cases, it is necessary to measure carefully the space required for the erection, so as to ensure

that sufficient room is available for the assembly, dismantling and handling of the parts.

LEVELLING OF BED PLATES

The engine bed plates must then be accurately levelled by means of a spirit-level supported on a parallel straight-edge placed across machined surfaces

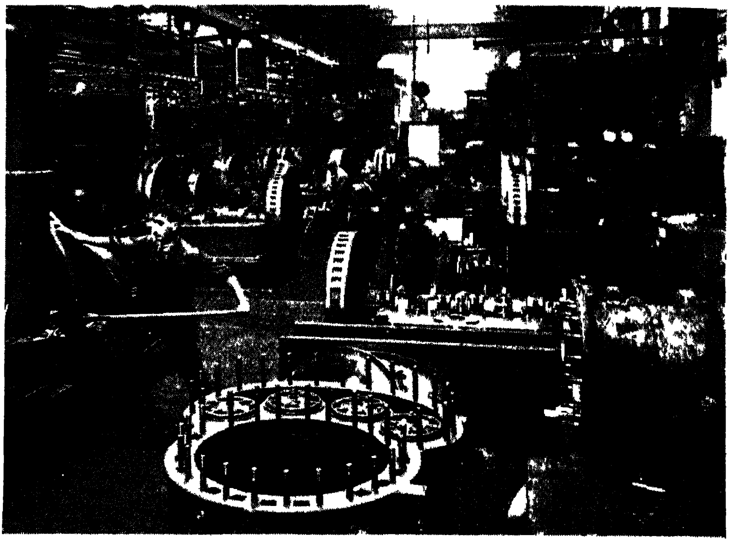


FIG 9 GENERAL VIEW OF THE ERECTING SHOP AT MESSRS BELLISS AND MORCOM

of the same height The spirit-level may easily be checked for accuracy by turning it end for end, and observing the position of the bubble The supports placed under the engine should be proportioned to the weight which they have to carry, so that subsidence does not occur during the course of erection. Metal packing pieces and wedges of adequate size may be used to adjust the level. Special attention should be paid to the supports of large horizontal engines,

particularly where two bed plates are concerned. In such cases the risk of distortion is greater than in the case of vertical high-speed engines, with their rigid, compact bed plates

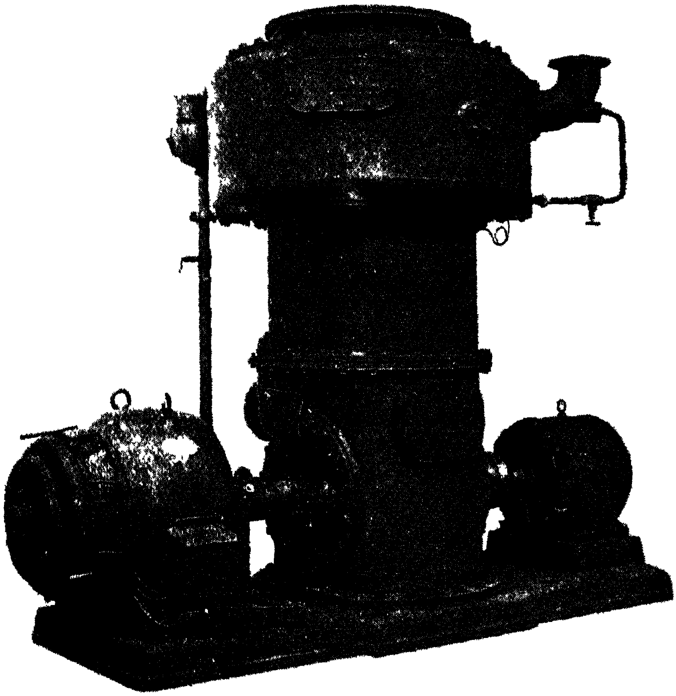


FIG 10 JET CONDENSER

CENTRE LINES DURING ERECTION

Strained lines of "piano" wire may be used to indicate the centre lines of vertical or of horizontal engines In both cases the ends of the cylinder bores are bridged by bars of wood or metal, and the lines passed through small holes at the exact centres The lower end of the vertical line is weighted and the

FIG. 11. ANOTHER VIEW OF ERECTING SHOP OF MESSRS BELLISS AND MORCOM SHOWING DETAIL ASSEMBLY WORK IN PROGRESS

weight immersed in a receptacle containing oil, so as to reduce the swaying of the line. The horizontal line may be supported, if necessary, at some intermediate point and the line may be strained by the application of weights at the ends. Strained lines are also used for marking lines across separate engine parts (e g. bed plates), so that the relative position of the parts may be reproduced when the engine is re-erected on site. The wire is placed across the parts, the ends weighted, and the line scribed and marked with a centre punch. Strained lines are of great use in securing the alignment and correct angular relations of the working parts, without which satisfactory and quiet running cannot be secured

ALIGNMENT OF ENGINES

The wide variation in the design of the various types of engines leads to separate problems in each case, but in many respects the general principles are the same. Thus, the cross-head, connecting rod and main bearing brasses require bedding to their journals and housings so that satisfactory clearances are obtained The adjustment must be such that the piston and connecting rods are in line, and the crankshaft is at right angles to the axis of the engine Careful fitting and scraping are required to achieve these results, and adjusting devices, such as liners and wedge adjustments, are provided in connection with particular designs In the usual design of vertical high-speed engine—where the cross-head guides are cast in one with the distance piece—automatic alignment is given, if the machining is good, by the spigots machined in the castings It is then only necessary to ensure that the centre of the bore comes above the centre of the crank pin when the latter is in a "dead-centre" position. Vertical engines with separate standards require perfectly fitted bases.

with guides at right angles to the axis of the crankshaft and parallel with the cylinder bore Crank pins must be parallel with the crankshaft and central with the axis of the engine Bed plates of cross-compound horizontal engines must be truly lined and levelled and, in all cases, cylinders and guides must be in line and at right angles to the crankshaft Any necessary modifications in the positions of cylinders and distance-pieces may be made by adjustment of the feet or flanges, and holes for fitted bolts or dowel pins should only be reamed when everything is adjusted and in line The details of design vary so greatly in individual cases that no general code is applicable to them all, and adjustments are frequently made to secure quieter working after an engine has been set to work In some designs efforts have been made to avoid the results of slight inaccuracies in the alignment by fitting spherical bearings. The engines illustrated in Figs. 3 and 4 have such bearings for the slippers of the main cross-heads and tail rod supports These engines also have main bearing brasses in four parts with wedge adjustments to facilitate the adjustment of the crankshaft

DETAIL FITTING

Apart from the careful alignment of the principal working parts, a great amount of detail fitting remains to be done during erection of the plant in the erecting shop Drain cocks, thermometer pockets, indicator cocks and lubricating connections, require fitting to the cylinders. Care should be taken to secure good joints by turning back the threads at the base of the screwed connections, or by slightly countersinking the tapped bosses. Piston rings require fitting with great care in order to avoid noisy working, leakage and breakage of the rings. For this purpose an allowance

FIG 12 VIEW SHOWING BELLISS AND MORCOM STEAM ENGINES IN VARIOUS STAGES OF ERECTION

is usually made on the thickness of the rings for the final fitting by hand. First, the grooves must be tried by means of a gauge and fitted so that the sides are true and parallel. The rings may then be scraped until they fit freely but without side play in the grooves, and the rings passed separately from one end of the cylinder to the other. Tongue pieces, stops, and springs also require fitting in accordance with the design, care being taken to allow sufficient clearance at the joints for the opening and closing of the rings. Piston nuts and cotters should be firmly secured and locked, so as to avoid knocking of the engine or damage due to any of the parts coming loose. Metallic packings are frequently fitted by representatives of the makers, who specialize and attain a high degree of skill in this work. If the piston rod is straight, true in section and finished to a good surface, however, there is no reason why the engine fitter should not undertake this work The packing rings should be carefully bedded to the rod, and all joints fitted with special care. In some designs, wiper glands with rings and springs are fitted outside the piston rod stuffing box to prevent the access of condensed steam leakage to the frame and the passage of oil to the metallic packing. These rings also require careful bedding and fitting, as considerable quantities of oil are sometimes lost, due to ill-fitting rings Connecting rod bolts should not be unduly strained in tightening up, and their heat treatment calls for skilful attention Detailed information on this point has been published in the annual reports of the British Engine and Boiler Insurance Company Incidentally, the reports of this and other insurance companies are well worthy of attention, as they contain detailed accounts of the characteristics and causes of breakdowns experienced with engines under actual working conditions Keys and keyways in all parts of

the engine require special attention to ensure that they are bedded properly on all sides This applies with special force to the keys securing the flywheel to the shaft These keys are subject to severe strains, and it is often necessary to drift or file the keyways in the boss and the shaft to ensure that they coincide exactly The fitting of valves and valve gear is also worthy of special care The precise methods vary in accordance with particular designs and it is necessary in each case that the fitter should study the functions and mutual reactions of the parts, so that surfaces may be fitted with the degree of accuracy necessitated by the working conditions. Pins, jaw ends, lever bosses, valve spindles, bushes, gears, shafts, rollers, seats and bearings, all require to be fitted so that the clearances and alignment are correct when the engine is heated up and expanded The setting of the valves should be in accordance with the valve diagrams, and it is a common practice to run the valve gear in the shop so that the exact position of the final key may be located, the functioning of the gear observed and hard places removed from the surfaces of the working parts During these runs the valve lifts, and piston positions at cut-off, steam admission, release and compression are observed and noted on the valve-setting diagram The appearance of an engine is greatly enhanced by well-fitted cylinder laggings ; care should be taken to avoid gaps at the edges of the planished steel plates and to ensure properly rounded surfaces free from tool marks Securing screws should make proper contact with the surface of the plates, and the bright beadings should not deviate from the correct angular relations with the cylinder. In fitting the governor and its driving gear, tight-fitting pins should be avoided. The importance of clear and adequate oil passages in accordance with the drawings is self-evident, and the

fitting of oil pumps is also of importance. Pipe work of all descriptions is also a feature of engine installations. Steam joints may be made by accurately scraped surfaces, or by the insertion of packings cut from suitable material In the first case the tightness of the joint depends upon the skill used in preparing the surfaces, and in the second case upon the suitability and accuracy of the packing In both cases the screw threads of the fastenings should be properly fitted and tightened. Water piping is not usually subject to high pressures and temperatures as in the case of the steam piping, but here again there is no excuse for ill-fitting joints, tight bolts, and projecting flanges. Small pipes for lubrication and water cooling are often run in suitable positions without the aid of detail drawings. In this case every effort should be made to secure short runs, freedom from awkward bends and neat disposition of the pipework. Cocks, valves, gauges and fittings should be placed in convenient positions, and they should be fitted so as to work freely, but without leakage. The clearances at the ends of the piston and air pump plunger may be tried by bringing the piston or plunger to extreme positions at the ends of barrels, first with the crank or driving pin brasses uncoupled, and, second, with these brasses coupled Corresponding marks made on the cross-head slippers and guides give the total possible movement of the pistons and the actual strokes respectively, and the distance between the marks at each end is a measure of the clearance

PAINTING AND DISMANTLING

When the cylinders are finally closed the engine should be slowly barred round to ensure that nothing fouls, and that all parts work without undue friction. When the final modifications are made the engine is

ready for inspection by the purchaser, and, subsequently, for painting and dismantling Castings to be painted are usually finished off neatly, rubbed down, stopped, and painted with two coats of paint prior to dismantling, the final coat of paint and varnish being given after erection on site When the engine is being dismantled, adjacent parts should be stamped as required to ensure erection in the same relative positions on site Otherwise, the operations are quickly completed and call for little comment, as the method of approach is dictated by each individual case. Care should, of course, be taken to avoid damage by forcing or mishandling of the parts, and important working surfaces should be protected from corrosion or damage prior to erection by painting, or by the fitting of protection boards.

OUTSIDE ERECTORS

The erection of steam engines on site is a skilled art, requiring considerable natural aptitude, practical experience, and resource Capable erectors are, in fact, somewhat scarce in most engineering shops. The reputation of a firm is dependent in no small degree upon the manner in which the erectors carry out their duties, and skill in such work has been the foundation of many successful careers. Outside erectors are, in effect, direct representatives of their firms and, in addition to practical skill in fitting and machining, it is necessary for them to understand the working characteristics of the plant and the intricacies of arrangement and foundation drawings. Powers of organization and tact are also necessary to facilitate the progress of erection and the relations with purchasers. Very few erections proceed according to plan, and the outside erector must have the initiative to devise measures to meet unexpected difficulties, such

as those caused by inadequate facilities on site, variations in arrangement, etc. Needless to say, he must also cultivate the strictest sense of punctuality, honesty, and business routine He is trusted with the expenditure both of his firm's time and money, and although he appears, frequently, to be forgotten at headquarters, his doings are, in reality, watched with special interest by those in charge of design and construction The ability to write concise and intelligible reports is a faculty of the utmost value to outside erectors Such reports should state the progress of erection, and they should give precise details of difficulties experienced in respect either of material or personnel Neat freehand sketches frequently convey greater information than the most voluminous report, and the erector should bear in mind that those who read his reports are, in general, exceedingly busy men who desire to understand his remarks in the shortest possible time Other points requiring the attention of outside erectors are—

(*a*) **Prior to Departure from Works.**

1. Collection and study of erection drawings and instructions

2. Dispatch of adequate appliances and tools in locked tool-boxes

3. Conferences with engineer's and dispatch departments, regarding scope of contract, details of delivery, etc

(*b*) **On Arrival at Site.**

4 Conferences with railway officials and purchasers regarding order and manner of delivery

5. Inspection of handling facilities, roadways, and access openings.

6. Checking of foundations and machinery house

(*c*) **During Erection and Starting-Up.**

7 Checking of advice notes with material received, and notification of discrepancies or breakages

8 Prompt return of packing cases.

9 Early advice to works of time at which sub-contractors may commence their portions of the work, e g. erection of electrical gear, fitting of packings, laggings, etc

10 Unloading, unpacking, cleaning, and arrangement of parts in positions convenient for erection

It is desirable that the erection should only be commenced in a reasonably clean and enclosed engine house and that all adjacent building work likely to cause dusty conditions should have been completed. Access openings in the walls may be covered, temporarily or permanently, as soon as they have served their purpose The erector in charge should set all centre lines and levels and should check the same periodically as erection proceeds Prior to starting up, the purchaser should be reminded to provide suitable and adequate supplies of lubricating oil and other stores. Erection drawings, tools, and appliances not included in the contract should be returned to the works when finished with. If the starting-up and tests are left to the erector-in-charge, it may be necessary for him to obtain from the works the required starting instructions, test instruments, and data sheets, and to organize the conduct of the tests Information regarding such tests will be found in Section XXXVI of this publication. Defects arising during the course of the tests will have to be rectified, and a final clearance certificate obtained from the purchaser It is apparent, from these notes, that capable erectors require to be sound practical engineers, and the acquisition of the requisite knowledge is worthy of the ambition of every good fitter. Apart from the interest and variety of such work, promotion to the higher positions frequently falls to the erection staff, and the scope and independence of work away from headquarters is of

the utmost value in promoting qualities of confidence and self-reliance.

FOUNDATIONS

The foundations of large steam-engines are complicated structures, calling for considerable ability on the part of those responsible for their construction. This will be apparent from Fig. 13, which shows a plan view of the foundations of a small horizontal engine. Generally, the foundation blocks of such engines are built upon concrete rafts of a thickness determined by the nature of the subsoil, revealed by excavations, and seldom less than 2 ft. thick The depth of the blocks varies from about 7 ft. for a 150 h p engine to about 13 ft. for a 2000 h p. engine Vertical high-speed engines are built upon concrete foundation blocks, projecting about 1 ft beyond the bed plates, and varying in depth between 3 ft and 8 ft. in accordance with the subsoil and the size of the engine Where several engines are erected in the same engine house, the foundation blocks are supported on a concrete raft from 2 to 3 ft. in thickness Two suitable methods of grouting these engines are available With the first method, the engine is levelled on metal wedges placed on both sides of each foundation bolt, so as to leave a space of $\frac{1}{4}$ to $\frac{1}{2}$ in. between the rough surface of the foundation and the underside of the bed plate A dam of clay somewhat higher than the underside of the bed plate is then built round the set, and a grouting of equal parts of Portland cement and clean sand is worked well into the space underneath the bed plate. The grouting must be well mixed, and the work must proceed continuously after the foundations have been damped on the previous night The second method is specially applicable when an engine and generator are disposed separately on the foundation block The

latter is first strickled and dressed to an absolutely level surface with a facing of quick drying cement (Portland cement and clean sand, 3 to 1). The underside of the bed plate is always planed to a true surface,

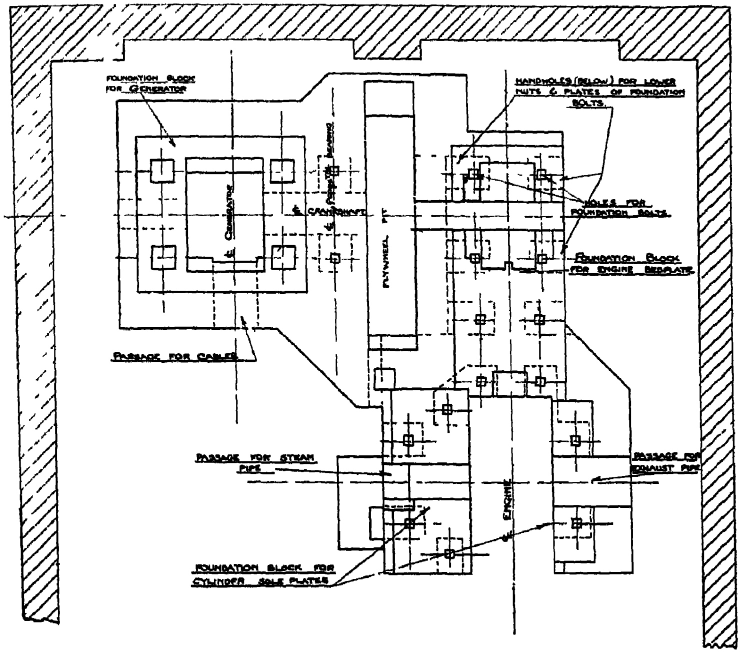


FIG 13 PLAN OF ENGINE FOUNDATIONS

and, when the set is in position on the prepared surface, the grout is fed through special holes, so as to act as a support for the metal which is not in contact with the foundations This additional grouting is required whichever method is employed With large horizontal engines, the bed plates may be levelled upon metal wedges placed between the underside of the bed plate and the foundation, and the space finally grouted or rammed with a ramming of Portland cement

and granite chippings, mixed by hand, with the minimum amount of water. A suitable concrete mixture for engine foundations consists of four parts of washed broken brick, one part of clean sharp sand, and one part of best Portland cement Shingle, rubble, Thames ballast, or slag may be substituted for broken brick if the latter is not readily available. The foundations should be kept clear of the walls so as to reduce the risk of transmitting vibrations to the buildings, and the design should avoid undercutting and weakening of the sections as much as possible Adequate openings are required for access to all parts requiring examination or adjustment, and the foundation for the generator should be continuous with that of the engine. Similarly, cleavage should not occur where provision is made for outer bearings and flywheel pits Foundations are also built of brick, or of concrete lined with brick, and old engines may even be found with stone foundations An example of brick construction is shown in Fig 5.

ERECTION OF HORIZONTAL COMPOUND ENGINES

The order in which the parts are assembled, and the details of the erection, vary in accordance with the design of the engine. As an example, the general procedure for the erection of a large horizontal engine is described in the notes which follow. The engine is of the type illustrated in Figs. 5 and 14, which give outside and sectional views, respectively Details of the liquid oil gear in the admission valve bonnets are illustrated in Fig. 15. All these illustrations are reproduced with the kind permission of Messrs. Galloways, Ltd.—the builders of the engine—and the notes regarding erection are in accordance with their general practice.

The engine is of the tandem compound type, with

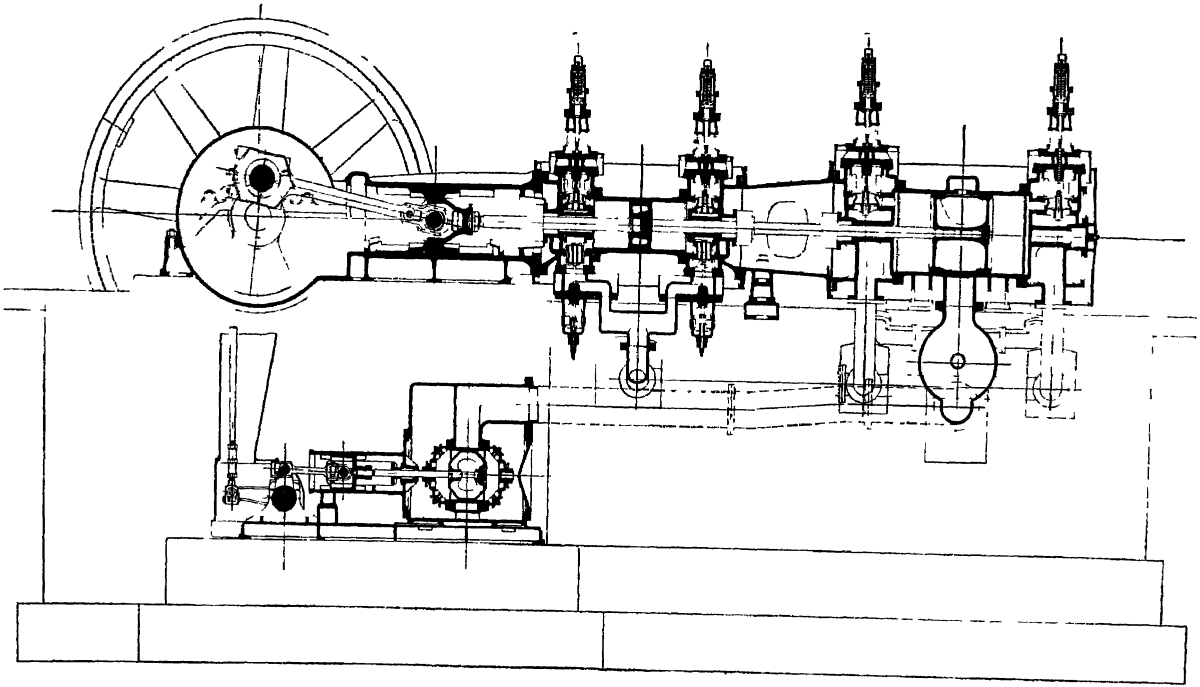


FIG 14. SECTION THROUGH "GALLOWAY" STEAM EXTRACTION ENGINE

four-valve H.P. cylinder bolted to the engine frame, and L P. cylinder of the Uniflow type separated from the H.P. cylinder by means of an intermediate distance

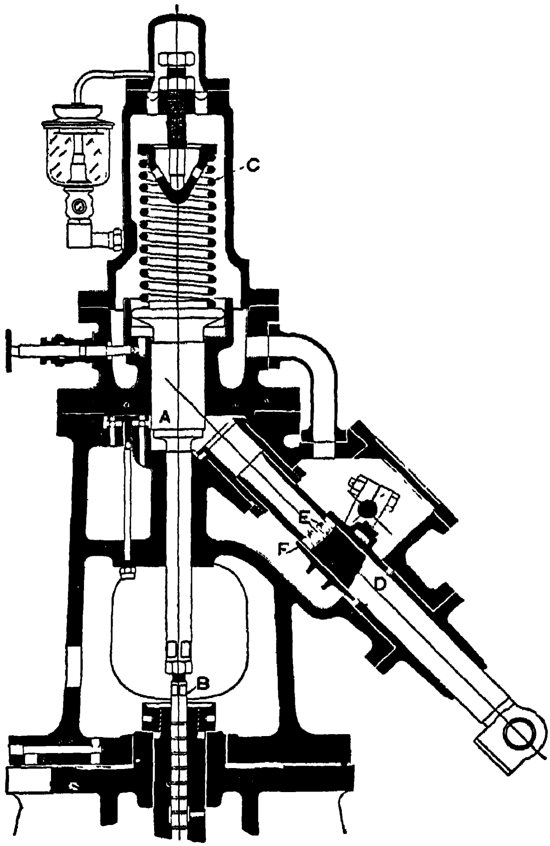


FIG 15 SECTION THROUGH VALVE BONNET OF "GALLOWAY" ENGINE

piece The crankshaft comprises a "sweep" crank supported in adjustable bearings on either side of the frame, and with a rope flywheel between the frame and

an outer pedestal bearing. The engine is designed for steam extraction through a process main, with non-return valve, connected to the intermediate receiver, and provision is made for the supply of make-up live steam from the boiler through an automatic reducing valve operated by the valve gear. The admission valves of the H P. cylinder are regulated by a centrifugal governor, so as to govern the engine speed, and those of the L P. cylinder by a pressure governor, which ensures constant pressure of the extracted steam.

ERECTION NOTES

1. Check over the foundation for height, length, and bolt-hole centres. The top of the foundation should be level, but not smooth Before grouting or ramming, the top of the foundation should be well watered to secure adhesion of the cement

2. Put bed plate on the foundation, having first prepared suitable iron wedges for levelling-up, and for raising the bed plate to the correct height ready for grouting or ramming

3 Put in the foundation bolts and level up the bed plate After the bed plate is levelled and in the proper position, permanent flat iron packing plates should be lightly driven in between the bed plate and the top of the foundation These permanent packing plates should be fixed close up on each side of each foundation bolt, and another good packing plate should be fixed immediately under the centre of the crankshaft Before grouting up, fill the bolt holes all round the bolts with dry sand, and lightly screw up the bolts on to the iron packings It is presumed that the centre line of the foundations is correct This centre line should be regarded as the permanent datum line of the engine bed plate, and the cylinders should be carefully fixed, exactly in accordance therewith The greatest care

should be exercised at all subsequent stages of the erection to see that the parts of the engine are set perfectly central, parallel, or square with the main centre line, as required.

4. Fix the H P. cylinder and front cover The cylinder will hang from the bed frame without support at the back end (i e. away from bed plate)

5. Fix the H P back cover, making sure that the joint faces are clean, but do not apply any boiled oil, as this joint has to be broken again in order to put in the piston (see paragraph 12)

6. Fix the base plate for the intermediate distance-piece and the distance piece itself, and by means of iron wedges raise the base plate until the H.P. cylinder is level and central Insert parallel packing plates under the base plate in exactly the same way as for the bed plate The steady pins in the bed frame and cylinder covers set the cylinder in one direction, and the level, the other way, may be checked by applying a straight-edge and spirit-level to the cylinder barrel.

7. Fix the base plates under the L.P. cylinder and place the cylinder in position, minus the back cover Level up the L P. cylinder in the same way as the H P. cylinder, care being taken that the base plates are set to the shop marks, so that there is room for expansion in the cylinder feet After the bed plate, H P. cylinder, distance piece, L P. cylinder, and the sub-bed plates are finally fixed, all these portions should be grouted up and allowed to set for a few days before the crankshaft is put in

8 Fix the outer pedestal bearing and sole plate and drop in the crankshaft See that the hoops for the fly-wheel are on the shaft.

9. The centre line should now be in position through the centre of the engine. A fixed pointer at least 3 ft. long should be clamped to the face of the crank pin

The crankshaft, with the pointer in line with the crank, should first be turned nearly on to the front centre, and the pointer set so that it just touches the centre line. It will not be possible to put the engine quite on to the front centre, as the crank pin will foul the centre line. The engine can then be turned on to the back centre, the centre line being removed for the purpose and replaced after the crank pin has passed The outer pedestal must then be adjusted until the pointer just touches the centre line, both in the forward and backward positions This shows that the crankshaft is perfectly square with the centre line At the same time the crankshaft should be carefully levelled by means of a spirit-level It is of vital importance that the squareness and the level of the crankshaft should be perfect The outer pedestal and sole plate can then be grouted up and the holding-down bolts finally screwed up in the same way as for the main bed plate

10 When assured that the shaft is correct—with the pedestal tightly screwed down—the next step is to proceed to build up the bearings. Drop the adjusting wedges behind the side steps, so that the latter are pressed lightly, but closely, home against the crankshaft After the pedestal caps are placed in position and have received a preliminary screwing up, the necessary clearance should be given to the side steps by raising the wedges half a turn of the adjusting screws. The pedestal caps can then be tightened up and the crankshaft revolved to make sure that it runs perfectly freely

11 Build up the rope flywheel, and fix the hand barring gear See that all flywheel bolts are well tightened, and that the hoop on the engine side of the boss is on this side before building up the wheel. Open out all the split-pins, and bar round to see that all is clear

12 Remove the top half of the intermediate distance-piece and the making-up piece under the bottom half This will allow the bottom half to turn round and lift away Draw back the H P. back cover, and put in the H P piston Thread the piston rod in from the front end, taking care that the metallic packings for the L.P front end and for the H P. back end are on It will be found easier to hold the H.P. back cover by the crane, when threading in the piston rod See that the cones of the piston and rod are clean, and tighten up the H P piston with the special spanner provided with the engine

13. Replace the H.P. back cover, care being taken that the joint is quite clean. Do not use a scraper to clean these joints, as they have ground faces. Make the joint with plain boiled oil and tighten evenly all round, after seeing that the steady pin is in position.

14 Replace the distance-piece and making-up piece

15 Put in the L P piston and tighten up as in the case of the H.P piston

16. Fix the L P back cover, taking the same care with the joints

17 Place in position the connecting rod and cross-head The same liners must be put into the connecting rod steps as are sent from the shop, and when all nuts are tightened it must be possible to give a slight side play to the rod by means of a small crowbar. Again bar round to ensure that everything is free.

18 Clean out the crankcase and fix the crank guard This will ensure that this end of the engine is enclosed and kept free from dust

19. Fix the exhaust valves and bonnets See that the valves and liners are well lubricated, and tighten up cover nuts evenly. Fix steam valve liners, valves, and bonnets The joints of the liners are ground, and only require painting with pure boiled oil.

20. Fix all steam pipes and exhaust pipes under the engine, as there is more room at this stage

21 Place the air pump in position, great care being taken that this is set correctly to drawing. This may be done by dropping a line down the face of the crank, for setting the distance from the centre line, and by setting the pump parallel to the engine line Couple up the pipes to the condenser, and fix the coupling rod to the crankshaft Before grouting down, bar the engine round and be sure that the clearance is the same at either end of the pump This can be determined without stripping the pump, as the shop "bumping" marks are plainly marked on the slide If the clearances are correct grout up the pump

22. Fix the layshaft brackets and the layshafts, great care being taken that the gear wheel on the crankshaft engages at the correct place on the layshaft wheel The correct position for this wheel is distinctly marked on the faces of the teeth

23. Remove the small oblong covers from the front of the valve bonnets, and assemble the eccentric rods and the rams Care should be taken not to damage the sliding valves in the bonnets, and to see that these are quite free when assembling Replace the oblong covers.

24 Fix the vacuum cylinder on the end of the camshaft, and make sure that the cams slide freely on the shaft Couple up the vacuum cylinder to the condenser

25 Assemble the governor pedestal and driving gear In doing this it will be necessary carefully to thread the worm into the wheel on the layshaft

26 Assemble the pressure regulating cylinder on the L P base plate

27 Fix the H.P and L P cut-off control shafts and the coupling rods to the valve bonnets These are all distinctly marked in the shop, and must not be changed.

28. Couple up all steam pipes, non-return back-pressure valve, and make-up reducing valve.

29. Fix the cylinder lubricator stand, and couple up the lubricating pipes from same These are distinctly marked in the shop, with their correct positions

30 The cylinders may now be warmed, and the engine run light before the covering is put on. When this is completed, fit the sheet metal cylinder laggings

31. Fit the main oil tank, rotary forced lubrication pump, and the oil pressure vessel on the bed frame Couple up the oil pipes to main bearings, and fix all other lubricators on the engine

32. Fix all drain pipes, special care being taken that the pipes are led away from the engine, and that the open ends are away from water.

33. **Liquid Oil Valves—Oil Filling.** Remove the oblong covers from valve boxes, and bar round until the ports in the ram are exposed Replace the cover and fill with oil from the top. This can be done by removing the top portion of the valve bonnet. Care must be taken, when filling, that the air screw on the box is well open. When the oil is half way up the indicator glass, replace the top cover, and bar round until the ports of another ram are exposed Fill in the same manner All four boxes require to be filled in this way. Bar round several times before closing the air screws, and then make quite sure that they are closed

34 Warm up the cylinders and pipes, and tighten up all pipe joints.

35. Fill all lubricators, and prime the oil pump by removing the adjusting screw on the relief valve.

36 Prime the condenser, and open the cylinder warming valves

37. Flush the cylinders with oil by means of the handle on the side of the mechanical lubricator.

38 Bar round until the engine is about one-third past the dead centre.

39 **Starting.** The engine is now ready to start up. Open the injection valve, see that all drains are open and warming valves closed. If the engine is past front dead centre, take the bar provided for lifting the valves to the front H P. valve Open the stop valve and, by means of the bar, lift, momentarily, the front H.P. valve. The engine will start immediately, and note should at once be taken that all valves are lifting

40 Close the drains as soon as the engine has attained full speed.

41 Should the valves hammer, throttle the oil under the dashpot by means of the adjusting screw on the back side of the bonnet

42 **Stopping.** Shut down after not more than an hour's run, by shutting the stop valve and breaking the vacuum by means of the vacuum breaker near the stop valve Open all drains and feel all bearings If satisfactory, start again and run light for a few hours.

43. Keep the oil level in the glass on the bonnet about half full Should it be necessary to strip any part of the bonnets, great care must be taken in re-assembling same, using only plain boiled oil to make the ground joints

44 In packing the glands for the valve spindles, use only a light spanner for the gland nut, as undue pressure of the packing retards the movement of the valve spindle In the latest designs packing is unnecessary

45 Should it be necessary, at any time, to examine the cylinders and pistons, the same procedure must be followed as described for the erection of the engine. It is not necessary to disturb the valve gear, except to uncouple the eccentric rods and control rods

46 It is not necessary after first starting-up to prime the condenser.

47 The engine can be started by lifting either the back or the front valve by hand, according to which centre the crank has passed.

QUICK REVOLUTION OR HIGH-SPEED ENGINES

Alignment of Crankshaft. The notes which follow in connection with these engines are in accordance with the general practice of Messrs. Belliss and Morcom, Birmingham, the well-known builders of this type, to whom acknowledgments are due for the use of illustrations and data. It is most important that the alignment of the crankshafts of high-speed engines should be carefully adjusted before finally grouting up. If the set is out of line the crankshaft is bent during each revolution, and will ultimately break either through the crank arm at *A*, or through the crank pin at *B* (Fig. 16).

The bending may be detected by measuring the opening and closing of the jaw of the crank at *C* In the case of an engine driving a single-bearing generator, the procedure during erection is as follows—

1. Level accurately and bolt down bed plate , add crankshaft and adjust bearing caps.

2 Erect generator on wedges, couple up and tighten bolts of main coupling.

3. Set crank horizontally, and apply point gauge—from circle marked at *D*—between webs of crank, so that gauge plus about $\frac{6}{1000}$ (feelers) fills the space.

4. Adjust tail bearing, horizontally and vertically, so that the opening at the jaw of crank is the same with the crank horizontally on either side of the vertical centre line, and at the " dead centres," respectively The engine should then turn freely by hand.

5. Slack off coupling bolts, insert feelers in the gaps of the coupling at *E*, and on the horizontal centre line. Ascertain that these gaps are equal

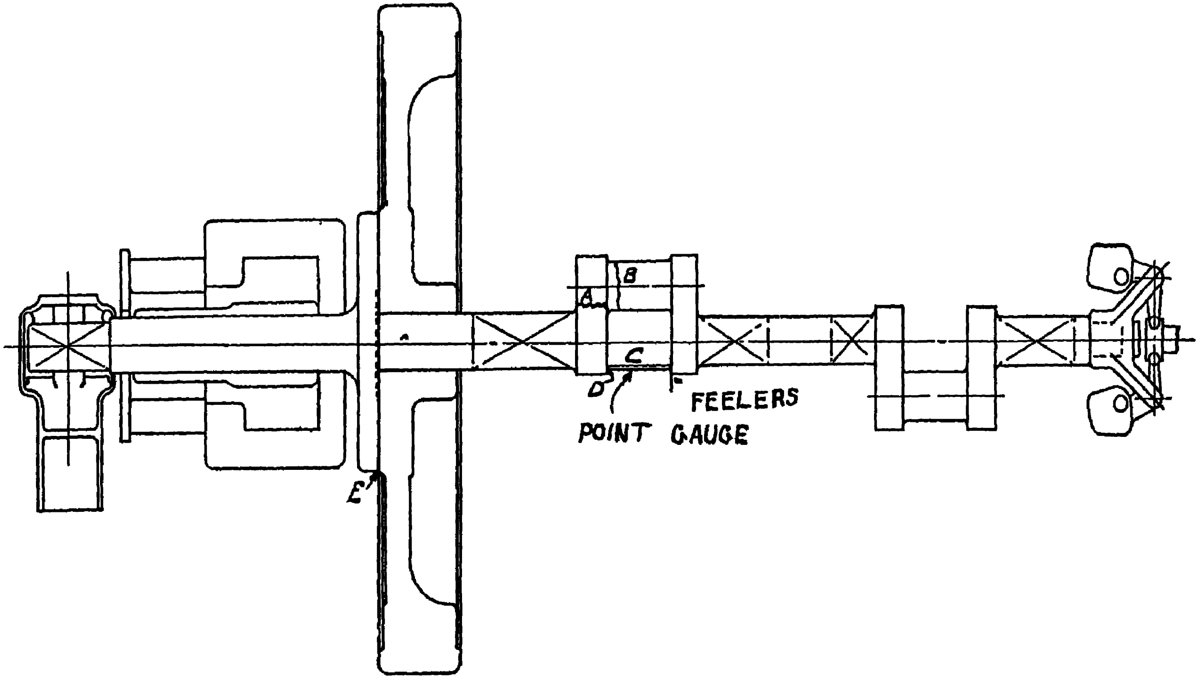


FIG 16. ALIGNMENT OF CRANKSHAFT OF HIGH-SPEED ENGINE

6. With the set correctly aligned and the gap accurately measured, stamp the magnitude of the latter on the coupling, for future reference. Sets lined up before dispatch from the shop already have this measurement stamped on the coupling.

In the case of an engine driving a generator with two bearings, the erection and connecting-up are the same as for the single-bearing generator, but the crank adjacent to the coupling should then be set at half stroke, and the dimension at the jaw of the crank measured with point gauge and feelers. The crank should next be placed on bottom centre, and the weight of the flywheel taken on wedges, or slings, until the dimension at the jaw is the same Finally, line up generator without any allowance for gap at coupling, remove wedges, check dimensions of gap in the four-crank position, slack off coupling bolts, measure gap, and stamp magnitude of the same on the coupling.

The alignment of the shaft should be again tested after grouting up, and for engines of over 300 h.p a third check should be made after two or three months' running

Setting of Throttle Valve Governor. The throttle valve governor of a high-speed engine is shown in Fig 17, and the throttle valve itself in Fig 18.

The governor is carefully set and tested prior to dispatch from the works, but if any check or readjustment is required this may be done, with the engine stopped, as follows—

1 Remove ball springs and speed adjusting springs, and ascertain that gear is free by moving governor balls by hand.

2 Note whether peg in governor valve spindle comes opposite mark *S*, with balls full open and mark *R* with balls closed (Fig 18).

3 With the balls fully open, the governor valve on

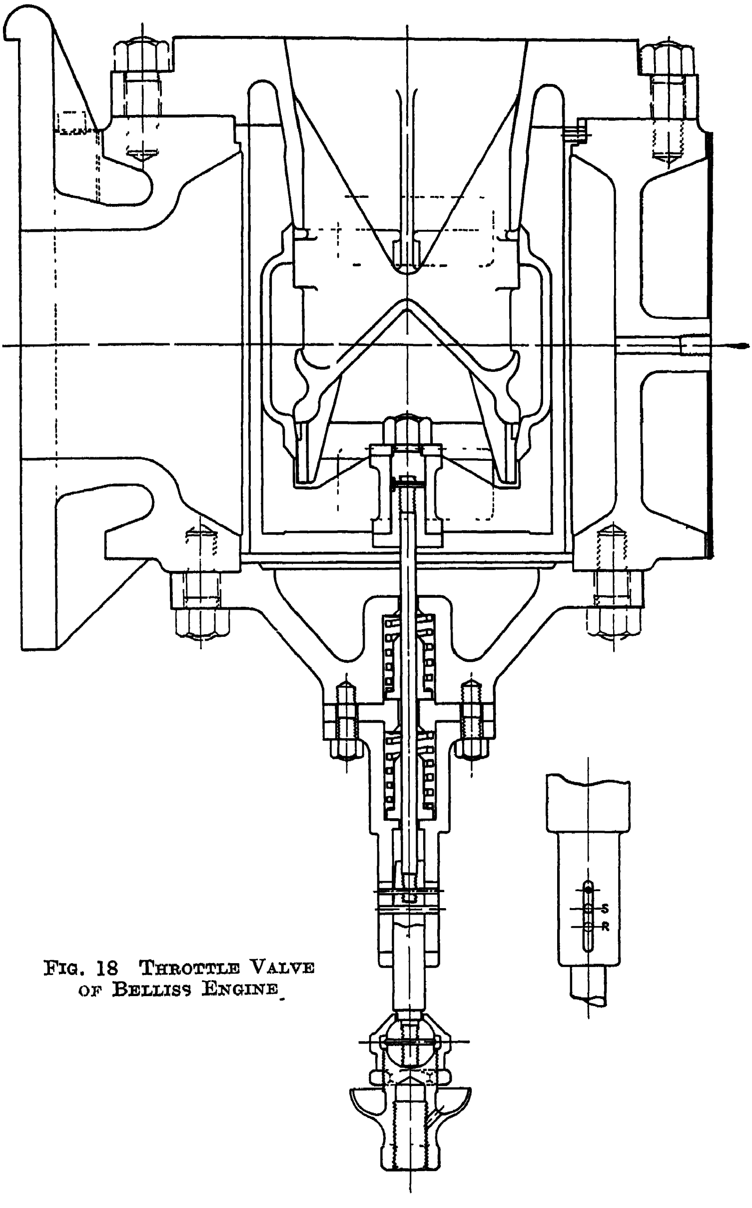


Fig. 18 Throttle Valve of Belliss Engine

its seat, and the line on the peg opposite mark *S*, there should be an appropriate clearance between the inner end of the governor sleeve 140, and the bracket 136 (Fig. 17) This allows space for any backlash in the gear, and so ensures that the governor valve definitely reaches its seat The clearance varies from $\frac{1}{16}$ in in the case of a governor measuring 5 to 7 in between the pivot pins of the balls, to $\frac{5}{16}$ in. for a measurement of 16 in., and over. If the clearance requires adjustment, this may be effected by removing the peg at the top of the vertical governor rod, and altering the length of the rod, as required.

SETTING OF PISTON SLIDE VALVE

This operation may be exemplified for the case of a "C" type two-crank compound engine, in which the H.P valve cuts off the steam on the inner edges and exhausts directly to the L P valve, which cuts off steam on its outer edges

The arrangement of ports and cylinders is shown diagrammatically at *A* in Fig 19, and the details given at *B*, *C* and *D* illustrate further the process of valve setting, described in the following notes—

Before putting the slide valve into the valve hole, a wooden staff of the ports should be taken To do this, a strip of wood about 1 in wide × $\frac{5}{16}$ in thick may be used, with a piece of sheet steel tacked on to one end, as shown in Fig. 19 *B*. The projections *A* and *B* on the sheet steel must be set at right angles to the lath, and must be in line with one another

The lath is now put down the valve hole, and the projection *A* rested on the bottom edge of each port. Corresponding lines are marked level with the top face of the cylinder Similarly, the projection *B* is rested against the top edges of the ports, the staff being marked, as before, from the cylinder top.

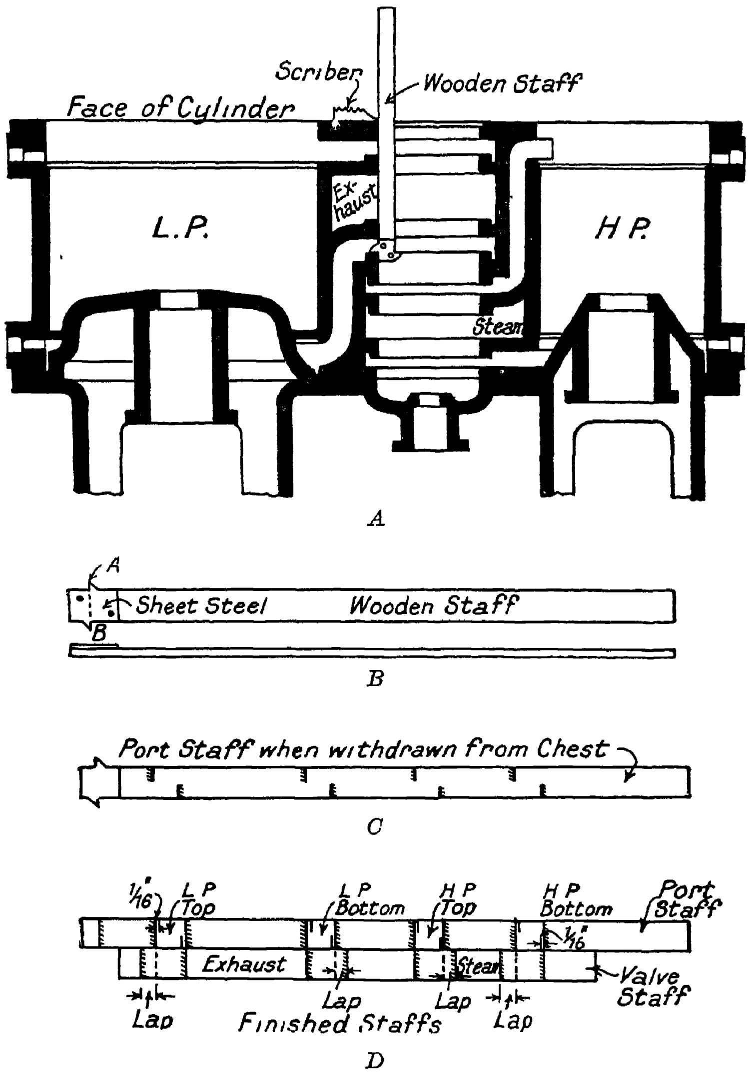


FIG 19 DIAGRAMMATIC LAYOUT OF PORTS AND CYLINDERS

It will be found that a piece of broken hacksaw is suitable for marking the staff, as shown in Fig 19 *A*.

Fig. 19 *C* shows the scratching marks on the staff when removed from the valve hole , $\frac{1}{16}$ in. should then be added on each edge of the ports to allow for the radius on the edges of ports and valve rings respectively. The staff should also be marked in line with the steel projections *A* and *B*, which, in the finished staff (Fig. 19 *D*), will represent the cylinder top face

A second and similar staff of wood should be placed against the port staff, and the port edges lightly marked upon it. The designed laps should then be added to the steam edges, as shown in Fig 19 *D* The lap and exhaust edges can now be marked plainly—using preferably, a square and a sharp penknife for the purpose. An exact facsimile of the ports and valves of the engine is now given by the staffs

Setting the Valve. In setting the slide valve, the valve should be checked over from the staff, to see that the edges of rings are correct A collar, of any thickness, should then be put on the valve rod, and the valve placed in position Next, the L P crank should be placed on top dead centre, and the distance from the cylinder face to the top face of the top ring accurately measured and noted

The two staffs should then be placed, side by side, in a position to give the designed lead to the L P top, and the distance from the cylinder face line to the top lap edge of valve ring should be noted. A comparison between the two measurements shows at once what modification is required in the thickness of the collar

As a check, the same procedure may be adopted with L P crank on bottom centre, and the setting for L.P. bottom tried over If the angle of advance of the eccentric is correct, the modification of the washer will be the same in both cases. If, however, the eccentric

is slightly out (e g suppose the L P. top shows $\frac{1}{4}$ in. to come off the washer, and L P bottom $\frac{3}{8}$ in), the mean of the two should be taken and $\frac{5}{16}$ in. taken off, which will alter the leads slightly on all edges

It will be seen that if the L P. valve is set correctly, the H P. valve must also be correct, as the valves move together as one mass, on the same rod.

WORK SUBSEQUENT TO STARTING-UP

The erectors of engineering firms are constantly in demand for the purpose of making running adjustments and repairs to engines supplied by their own or by other firms The details of the work vary in accordance with the circumstances of each case, but the adjustments are most frequently connected with bearings, piston rings, packings or valves Similarly, engine fitters engaged in factory maintenance are called upon to undertake similar adjustments It is not possible, in the scope of a short article, to deal with all possible variations, but details of the principal adjustments in the case of high speed engines of the Belliss type are given in order to make clear the general routine. It is desirable that engines should be opened up for inspection and adjustment by a competent erector at least once in every twelve months This course amply repays the expense involved, both in respect of the reduction of wear and tear and of the avoidance of breakdown The period may be varied in accordance with the working conditions—engines running continuously under exacting steam conditions requiring adjustment more frequently than those operating under ordinary conditions

ADJUSTMENT OF BEARINGS

If the maker's working instructions, and especially those in connection with lubrication, have been attended to, it will be found that the engine, after first

adjustment, runs for prolonged periods practically without wear of the journals. If, however, it is found necessary to adjust the bearings, the work should be carefully done, so as to prevent the oil subsequently escaping too freely For this reason bearings should not be eased away at the sides, as is usual with open type engines It will be found that on the Belliss system of lubrication it is possible to run the bearings with much closer adjustment than usual. The shells should be let together by filing the edges, or by taking out liners, as the case may be, taking care not to remove too much, so that when adjusted the shells butt, and the nuts can be screwed hard down on the caps without nipping the journals.

The fact must not be lost sight of, when re-white-metalling or adjusting bearings, that two of the main bearing shells are specially white-metalled at one end to form thrust bearings designed to take up the end play of the shaft

After adjusting the bearings of connecting rods, it is necessary to see that the rods are working centrally when tightened up ready for running, while the engine is turned round by hand. There should be a clearance between the sides of shells and crank webs, and between cross-head shells and connecting-rod jaw, and the piston should travel centrally in the cylinder from top to bottom of stroke, not touching the cylinder walls. If it does not travel centrally, the shells must be scraped in the crown until the rods are central and the foot of the connecting rod and top face of crank shell are fair, face to face.

MOTION BOLTS

The motion bolts are made of specially toughened steel, and if a bolt should break it is almost invariably found to be due to some special cause, as, for

instance, the nuts on the companion bolt having slacked back, throwing all the stress on the bolt which has broken It is a moot point as to what extent motion bolts become affected by "fatigue," but it is good policy to replace bolts which have been in use for, say, 10 years , also, to replace bolts which have been subjected to any considerable shock (as from water in the cylinder) likely to start a crack It is good practice to have a spare set of motion bolts and to change them over at the annual overhaul, to ensure that the bolts are properly examined at least once every twelve months, and to give the bolts a rest.

NUTS ON MOTION BOLTS

In view of the serious consequences which may result from any of the nuts of the motion work slacking back, especially the bolts on the cross-head and crank-pin bearings, it is very desirable and necessary that these and any other nuts on the motion work should be periodically examined to make sure that the nuts are tightened hard up and have not started to slack back, and that all split pins are in place

In the case of engines which are shut down at the week-end, the doors should be removed and an inspection made every week Where the engines are run continuously, no opportunity should be omitted of making an inspection at least every three months If there is any noise suggesting that a nut may have slacked back, no time should be lost in making an inspection When the engine is overhauled, or any adjustments made, great care should be taken to see that the nuts are tightened hard up and properly locked, and that the split pins are securely fastened.

It is natural during the first two or three days a new engine has been put to work that the various parts should adjust themselves one to another, and minute

stretchings and movements occur which should be allowed for and followed up

The engine should not, therefore, be put on continuous duty straight away, but after the first few days it should be shut down, and all nuts on main bearing studs, motion bolts, etc., tried with a spanner, so that any slackness may be taken up

HOT BEARINGS

After running for some time the bearings will acquire a uniform temperature of 120 to 180° F, due mainly to heat passing down from the cylinders.

With the system of forced lubrication adopted, however, a hot bearing should be an impossibility, unless the bearing has recently been set up too tightly, or the oil supply has failed through dirt or otherwise. If, however, the white metal is found to have run slightly, the bearing should be re-bedded on the journal by scraping. If the white metal has run badly and requires renewal, the bearing should be returned to the makers, unless adequate facilities exist near at hand.

HOT PISTON ROD

A hot piston rod is found, almost invariably, to be due to the presence of dirt, and the first opportunity should be taken for cleaning and adjusting the packing.

If the rod becomes hot, additional lubrication should be given and, if possible, the engine should be kept turning slowly until the rod has cooled, and the cause of the trouble should then be carefully sought for and remedied If the rod has been hot, it should be tested to see that it has remained straight

REMOVING PISTON FROM ROD

If it is possible to remove the cover quickly after the engine has been running, and to get a strain on the

piston, it is very probable that it will be started without trouble, but if not, proceed as follows—

First, place a good heater on the piston and apply as much strain as possible by means of the special forcing-off appliances provided. Apply paraffin oil or vinegar freely to the screwed part of the rod above the piston.

Next, remove the top half of the crank pin brass, and screw up the cap nuts about $\frac{1}{4}$ inch, or as required, to take up the clearance at the bottom stroke The piston will now rest on the cylinder bottom when the crank is almost, but not quite, on the bottom centre. If one or more men are now set to pull on the turning gear and, at the same time, some sharp blows are given to the top of the piston rod, the probability is that the piston will be released from the rod without further difficulty

PISTON RINGS

L P piston rings will, as a rule, run for years without adjustment, but they should be inspected at the time of the annual overhaul to see that they are in good working order, or at other times, if they work noisily The same remark applies to intermediate pressure piston rings If trouble or excessive wear occurs with these rings, it is generally because undue use is made of the by-pass valve, or the H P piston rings are out of order and passing steam

The H P piston rings should be well looked after If neglected, not only will trouble result in the H P cylinder, but the intermediate and L.P rings in turn will become affected, so that any attention given to the H P. rings is well repaid The H P piston rings are designed on the restrained principle, and are nowadays made of cast iron if the steam is saturated, but if the steam is at all highly superheated, or the engine has to run without internal lubrication, a special alloy of

bronze is used The advantage of the bronze is that its use is attended by a great reduction in the coefficient of friction, the wear of the cylinder barrel being very slight. With cast-iron rings, if excessive wear occurs, the cast-iron particles not only increase the wear in the H.P cylinder, but they pass through the engine, causing trouble with the other cylinders and metallic packings. The restraining edge of the piston ring is a great safeguard against excessive wear. In the absence of the restraint the rings do not require such frequent adjustment, but the wear proceeds unchecked, and the cylinder may be badly damaged and require reboring or even replacing before the trouble is diagnosed With the restraint, if wear occurs the rings get on to the restraint, when the piston, being deprived of support, knocks in the cylinder, calling attention to the need of adjustment. In such a case proceed as follows—

Remove the cylinder cover, try with feelers the clearance (if any) between the piston ring and the cylinder. Remove the junk ring Note the opening at the butts of the rings in the carrier ring Remove the rings and try them separately in the cylinder, noting again the opening at the butts If the opening of the butts in the cylinder is greater than when in the piston, it is obvious that the rings are on the restraint, and the restraining edge of the rings must be filed until the opening at the butts, when the rings are in the carrier ring, is, say, $\frac{1}{8}$ in greater than when the rings were tried in the cylinder. If the rings will not open so much they must be carefully expanded by light blows with the pein of the hammer, on the inside This is an operation requiring some skill, and should be carefully done so as to ensure an even stretching of the metal, the blows being distributed over a considerable area but mainly opposite the butts. If not carefully done, the rings may become broken or, by

hammering nearer one edge than the other, the ring may be twisted.

The operation is usually carried out by putting the ring on a flat, smooth, solid surface, such as a good anvil face, or the end of a lathe bed, and hammering the inside of the ring with the pein end of a light hammer. If the rings require too frequent adjustment the wear is excessive, suggesting that the material of the rings is unsuitable.

When new piston rings are required, a point gauge made to the smallest diameter of the cylinder should be sent to the makers, together with a complete gauge sheet of the cylinder bore. A specimen gauge sheet filled in is shown in Fig. 20

It is important to see that there is sufficient opening at the butts to allow for expansion. The usual clearance is $\frac{4}{1000}$th of an inch per inch diameter of the cylinder, plus $\frac{15}{1000}$th for cast iron and $\frac{10}{1000}$th per inch diameter plus $\frac{30}{1000}$th for bronze, the tongue piece to have $\frac{1}{64}$th clearance at the end when the piston rings butt. In the case of restrained or other rings, which fit closely in their grooves, there must be sufficient allowance to prevent their setting fast in their grooves by expansion.

The carrier ring should be a good fit in the cylinder, the usual allowance of clearance when new as tested by a feeler thrust in on one side being $\frac{3}{4}$ of a thousandth of an inch per inch bore of cylinder

It must be borne in mind that it is useless fitting new rings into a cylinder which is badly ridged or barrelled and requires reboring

Portable boring machines may be used for boring out the cylinders and valve chests, if they have become worn after years of service

GAUGING CYLINDERS AND VALVE CHESTS

It is an excellent plan on receipt of a new engine or,

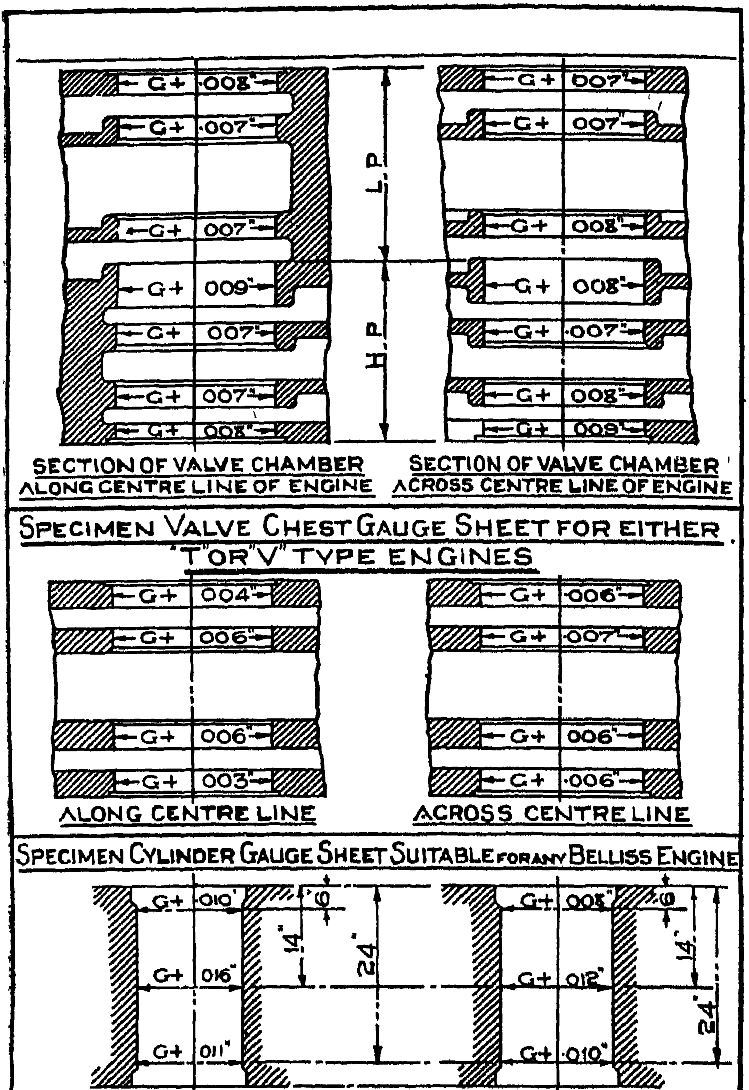


FIG. 20. SPECIMEN GAUGE SHEET FOR BELLISS ENGINES

indeed, at any time, to make point gauges for the bore of cylinders and valve chests, and thereafter at each overhaul or other convenient opportunity, to note by means of feelers the wear which has taken place, and to keep a record in a book. A specimen gauge sheet is shown in Fig. 20 The information thereby obtained is exceedingly useful when ordering replace piston or valve rings

ADJUSTMENT OF SLIDE VALVES

Apart from the valve setting, which has already been dealt with, the adjustment of the slide valves themselves is a matter requiring attention. These valves have considerable weight, and in the course of time they are liable to work loose between the washers on the rod. They should, therefore, be examined as opportunity offers or as may appear requisite, but at least every six months, and any slackness there may be taken up by adjusting the nut. In the case of H P valves which rotate and have a distance piece, the nut can be screwed up tightly, taking care to see that the valve is still free to rotate The nuts securing intermediate and L P slide valves should not be too tight. The packing rings are also liable, in course of time, to work slack vertically, and to rectify this the valve must be removed from the engine and the junk rings let down, leaving the rings so that they can be just moved by a tap from a hammer shaft The rings, if worn on the face, should be eased by filing the restraining edge on the ring, allowing them to expand, but leaving them just on the restraint and out of contact with the valve chest The valve rings must not be let out of the restraint so much as to bear on the valve chest or, when hot, the valve may seize owing to expansion.

Solid valves must have sufficient clearance to prevent their seizing in the bore, the amount of such clearance

varying with the temperature of the steam New slide valves are sent out from the shop with a label giving the correct clearance.

REPLACE SLIDE VALVES

When a replace slide valve is required it is advisable to take a careful gauge of the valve chamber, so as to ensure that the new valve will be of the correct size, as a certain amount of wear may have taken place in the chest after prolonged running

The specimen gauge sheet in Fig 20 may be used when ordering new valves.

PACKING OF STUFFING BOXES WITH SOFT PACKING

It is important that this operation should be carefully performed Metallic packing is fitted, except in the case of the L P. stuffing boxes of smaller engines, where soft packing is used For the latter, pure plaited asbestos and graphite is most suitable, and it should be applied in separate rings and uniformly disposed round the rod , care being taken when tightening up the glands to screw up the nuts on the gland studs equally

The asbestos packing should be of the right size for the stuffing box, and not reduced by hammering, as is usual with some packing.

The packing should be treated with blacklead and cylinder oil before placing in the stuffing box, and it should be merely stemmed tightly in the stuffing box, and not screwed up at first, as it requires room to expand It is also necessary to allow each turn to be open $\frac{1}{8}$ in at the butts. The joints should be arranged uniformly round the rod.

The steam will be found to pass through at first, but the packing will take up after a short time.

All soft packings should be run on the slack rather than on the tight side, but the packing of the L P. piston rod should be kept well adjusted to prevent air leakages and passage of oil into the cylinder.

After about three months' continuous running, the packing should be withdrawn for examination, the good turns being replaced in the stuffing box and new packing substituted for any which has become worn out or burnt ; the new packing to be placed next the cylinder Care should be taken that no worn edges come next the rod, as they are liable to unwrap and cause trouble. The foregoing remarks apply also to most other kinds of soft packings

METALLIC PACKING

The metallic packing of standard "Belliss" design is steam packed, with floating boxes, self-adjusting ball rings, and segments of high melting-point mixture for rods subjected to the full steam pressure and temperature, and low melting point mixture for other rods.

If leakage occurs at starting it may take up with running, but otherwise it is probably due to dirt, and the segments should be cleaned and, if necessary, carefully bedded to the rods

For the satisfactory operation of metallic packing, it is essential that the rods should be true and if, after continued use, the rod is worn out of shape, it should be ground true before applying new segments If the diameter is reduced more than $\frac{1}{16}$th of an inch below the original size, new floating boxes and lids will be required.

When replace packing is ordered, it should be stated whether it is to suit the original dimensions of the rod, or, if not, a gauge or micrometer measurement for the reduced size of the rod should be furnished When

fitting replace segments, care should be taken that the corresponding numbers on the segments come together, also that the segments break joint and that there is sufficient clearance at the butts, the space between each segment being not less than $\frac{1}{16}$th of an inch. If any of the springs have taken a permanent set they should be replaced

PUMPS

Pumps of one sort or another are to be found in practically every department of industrial and municipal practice They are used for the water supply of large towns, the drainage of mines and tunnels, the generation of hydraulic power, and for a whole host of auxiliary purposes connected with the efficient transference or circulation of liquids in factories, power stations, and domestic establishments

TYPES OF PUMPS

There is an extensive range of designs available, varying from the small hand-operated or rotary pumps, used for filling tanks and emptying sumps, to the large power-driven sets found in pumping stations, docks, irrigation works, etc A complete classification would occupy space needlessly, but a selection of the more common types of pumps found in practice follows—

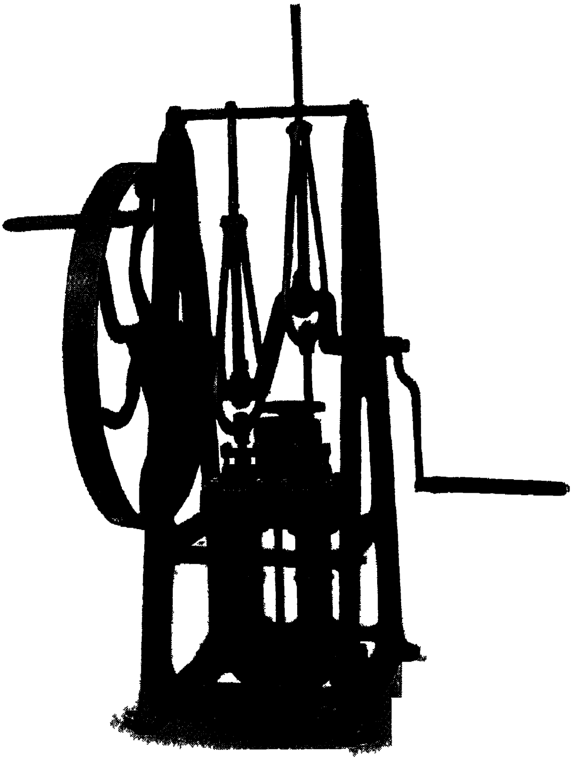
(*a*) A range of hand-operated reciprocating pumps for miscellaneous pumping purposes, one form of which is shown in Fig 21

(*b*) A series of power-driven reciprocating pumps for general industrial purposes, similar to that illustrated in Fig. 22.

(*c*) Multi-ram pumps of the horizontal or vertical patterns for the unwatering of mines and the production of hydraulic power (Figs 23 and 24).

(*d*) Direct-acting reciprocating pumps for boiler-feed purposes, as shown in Fig 25.

(*e*) Power-driven centrifugal pumps for low, medium,

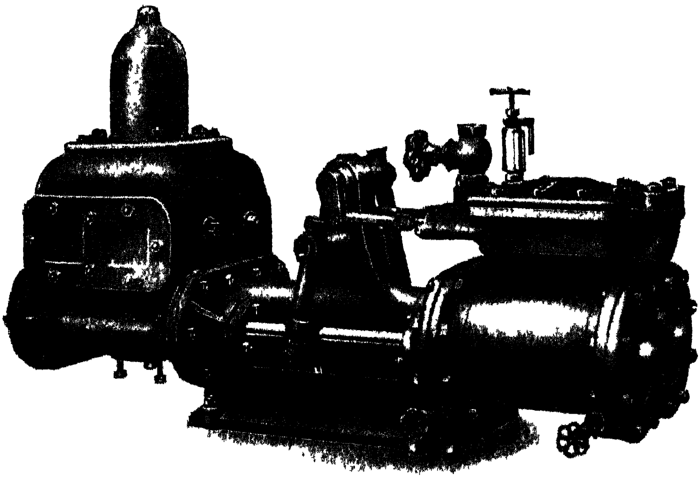


(*Jos Evans*)

FIG 21 HAND-OPERATED DOUBLE BARREL RECIPROCATING PUMP

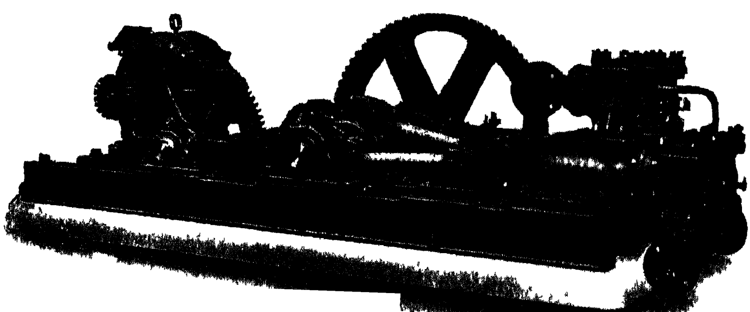
and high heads, suitable for all continuous pumping processes and for boiler feeding (Figs. 26 to 28).

The illustrations of reciprocating pumps are by courtesy of Messrs. Joseph Evans (Wolverhampton),



(*Jos Evans*)

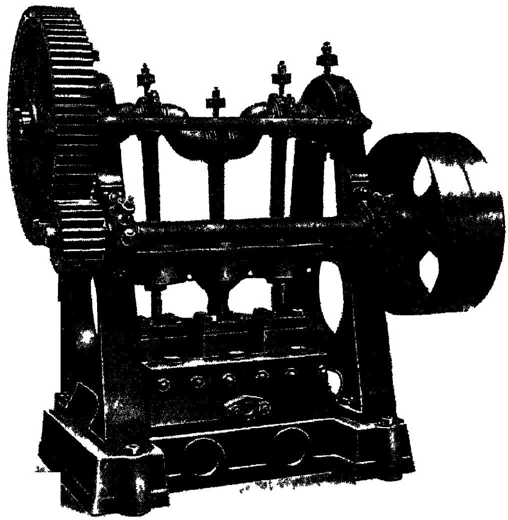
FIG. 22 STEAM DRIVEN DUPLEX RECIPROCATING PUMP



(*Jos. Evans*)

FIG. 23 HORIZONTAL TREBLE-RAM PUMP

Ltd., those of centrifugal pumps, Messrs Mather & Platt, Ltd., and the boiler-feed pump, Messrs. G. & J. Weir, Ltd —all leading British makers of high-class pumps. The requirements of municipal water supply necessitate a further class of large reciprocating pumps



(*Jos Evans*)

FIG 24 VERTICAL TREBLE-RAM PUMP

driven by vertical triple-expansion condensing engines. Many fine installations of this type have been constructed by Messrs. Worthington Simpson, Messrs Hathorn-Davey, Ltd., and other leading firms

CONSTRUCTION AND MANUFACTURE

The illustrations show that all the pumps classified under types (*a*) to (*d*) are produced by the assembly of a number of detail parts such as shafts, bearings, plungers,

valves, gears, and the like. The manufacturing processes, therefore, lend themselves to a high degree of standardized design, and most firms adopt production methods in their workshops. A common practice is to put through the shops at the same time a number of pumps of similar design, and to rely upon the normal trade demand for the subsequent sale of these pumps In this way manufacturing costs are reduced by the lowering of overhead charges consequent upon mass production Complete sets of working parts are passed from the machine shops and collected in the erecting shops before fitting and assembly are commenced Subsequent operations are sometimes carried out at ordinary day-work rates with bonuses for production above predetermined amounts, or piece work systems are adopted Pumps such as those described are dispatched to all parts of the world, and erection on site has frequently to be performed by men with the most elementary knowledge of mechanics The designs

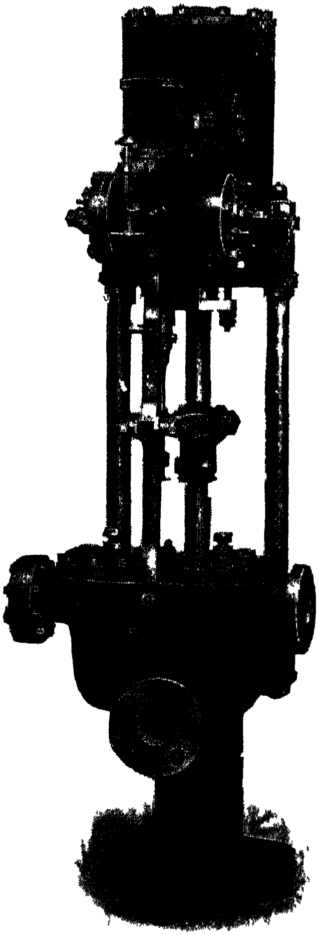
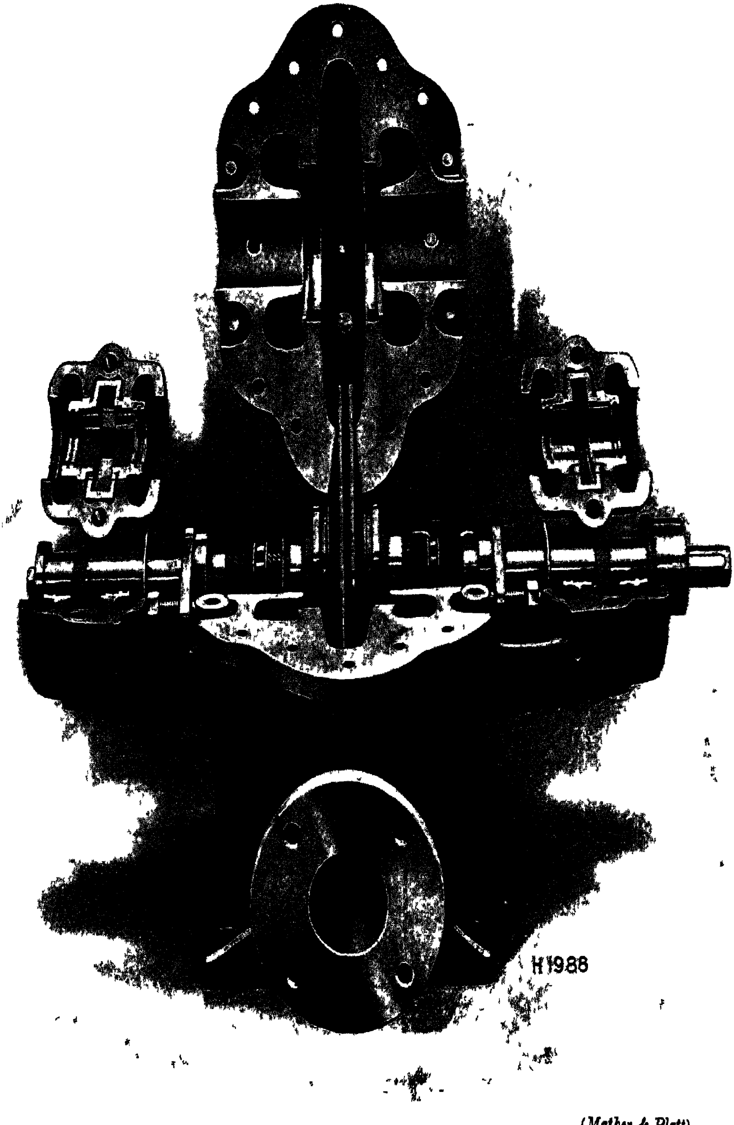


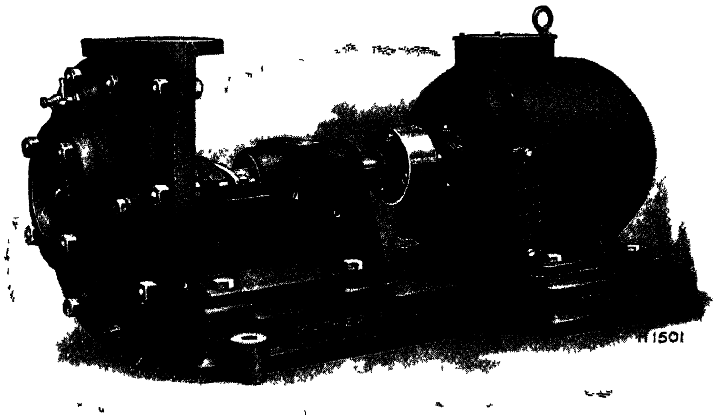
FIG. 25. "WEIR" BOILER-FEED PUMP



(*Mather & Platt*)

FIG 26. MEDIUM-LIFT CENTRIFUGAL PUMP

are, therefore, usually such that adjacent parts are recessed and nippled so that automatic alignment is ensured, and the necessity for skilled erection on site minimized For the same reason, squared-out recesses or dowel pins, fitted after assembly is complete, are avoided Where nipples and recesses are not possible, turned bolts fitted in reamered holes



(*Mather & Platt*)

FIG 27 LOW-LIFT CENTRIFUGAL PUMP

are adopted Even with these methods, however skilled erectors of the highest class are required for the erection of certain types of pumps Multi-stage centrifugal pumps are preferably erected by skilled erectors, and large waterworks pumps driven by steam-engines call for the greatest care in the alignment of the engines, the bedding of the bearings, and the setting of the valves and valve gear Reciprocating steam driven pumps of the "Sinking" type also require skilled attention during erection on site, to ensure that the parts are correctly aligned, and that all clips securing water, steam or exhaust pipes are an easy fit on the

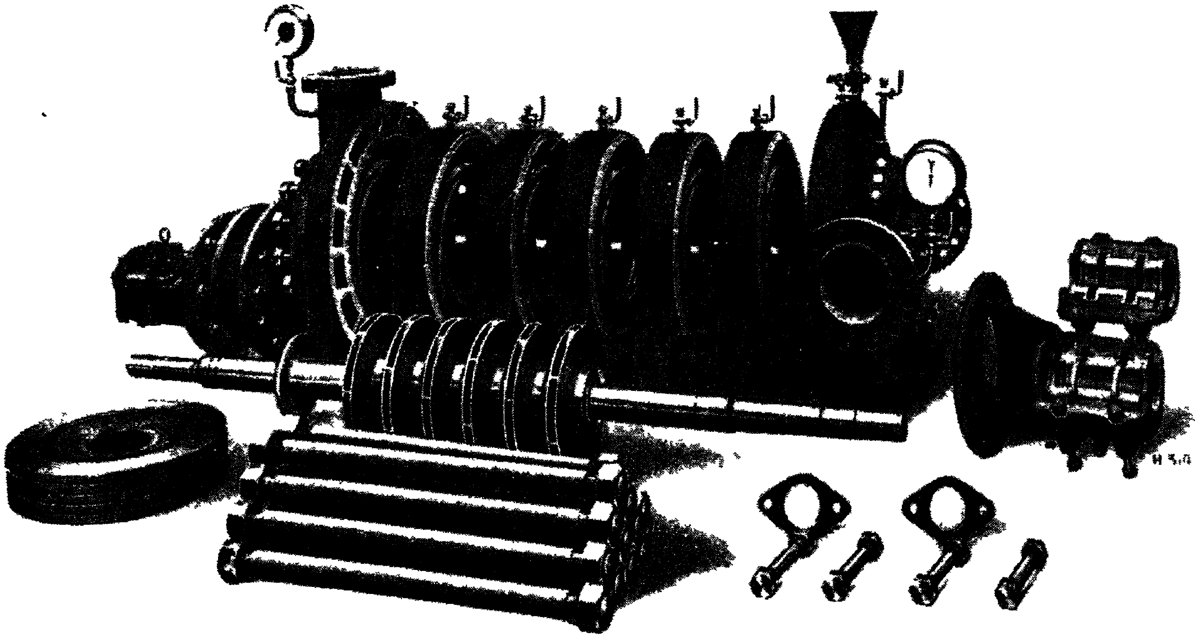
pipes, so that strained joints and broken flanges are avoided.

FITTING

Modern machining methods reduce to a minimum the amount of work which remains after the parts have been delivered to the fitting and erecting shop The multiplicity of such parts is well illustrated by Fig. 29, which is a view taken in the works of Messrs Joseph Evans (Wolverhampton), Ltd. This illustration shows the general disposition of the shop for the economic production of large numbers of standard pumps. Partly assembled units are shown in transit between the benches and in course of assembly The operations incidental to the fitting of keys, rods, and studs, the scraping of working surfaces, and the fitting together of the component parts, are illustrated by the details on the benches and in the vices. The work in the shop is principally centred round these operations, and brief notes referring to the same are appended

KEYS

These keys will usually be tapered keys with gib heads, or sunk keys with rounded ends. As a rule, the keys are received machined to size from the machine shops, but if they are rough forgings only they must first be filed carefully to a size suitable for the keyway. It is then necessary to examine and gauge the keyway and correct errors and remove sharp edges left by the machining process Tapered keys with gib heads must be a close fit on all four sides, as hard bearing places in isolated spots lead to slack fits. The accuracy of contact may be checked by smearing the groove with red lead or oil, and driving the key lightly home so that the hard places are clearly indicated. The fitting of the sides and underside of the key should



(*Mather & Platt*)

FIG 28 HIGH-LIFT CENTRIFUGAL PUMP

be performed first—care being taken to ensure that the sides are parallel and at right angles to the faces, and that the contact of the sides is not such as to necessitate a driving fit. The tapered face of the key may then be fitted The rounded ends of sunk keys should be filed to make satisfactory contact with the ends of the groove, and the sides of the key filed to secure a close fit in the groove Accurate contact between the underside of the key and the bottom of the groove is also necessary, and may be gauged by the character of the sound when the key is tapped home In all cases, care must be taken to exclude filings and grit before keys are driven home During the fitting process the keys should only be driven lightly home, and oil should be used to facilitate removal Gib-headed keys may be removed by the use of a key drift, or by inserting a wedge between the head and any adjacent boss.

The accuracy of the bore of the boss should be such that the wheel is not constrained to move out of truth when the key is finally driven home

TOOLS

The accuracy and speed of fitting operations are greatly affected by the character of the tools used and the general system of operation of individual fitters. There are, in nearly all workshops, selected groups of men whose work outstrips that of their fellows in respect of the points mentioned. If these cases are examined, it will often be found that a good deal of their success is due to the acquisition of a good set of tools kept in perfect working order, and to an ordered manner of approach to the various operations. Good work cannot be performed with inferior tools, and as chisels, scrapers, and similar tools vary greatly in their characteristics, specially good specimens should

FIG 29 PORTION OF ERECTING SHOPS OF MESSRS. JOSEPH EVANS (WOLVERHAMPTON), LTD.

be earmarked with the object of forming a collection which will permit of the very best work. This collection should include calipers, feelers, centre punches, scribers, rules, and simple gauges, as well as flat and round scrapers, files and chisels of various kinds Time need not then be lost during the progress of the work, and it will not be necessary to borrow from other individuals in the manner which is so common in many shops A suitable tool-box with a good lock is an essential complement to such a set of tools, as nothing goes so easily astray in a workshop as a really good tool. When a collection has been made, the tools should be kept clean, sharp, and in good order, and they should always be sharpened after a job is completed, so that everything is in readiness for the next piece of work.

METHODS

Similarly, the results are bound to suffer if the work is hurried or arranged in an inconvenient manner A good fitter is distinguished by the care and thought he bestows at each stage of an operation Good fitting is a skilled art, and as such requires both manual skill and orderly precision in the arrangement and checking of the work as it proceeds. It is almost impossible to do good work at a bench encumbered with odds and ends of all kinds, with incomplete or faulty tools, and without forethought as to the manner in which the work should proceed. The services of a good mate are also of great assistance in securing speedy and comfortable progress, and by a little judicious scheming a fitter may usually contrive to secure a mate who understands his method of working, and can practically anticipate his requirements as the job proceeds. Vice clamps of wood and metal should be kept handy, together with small vee blocks, filing blocks, and similar appliances used in bench operations.

CHIPPING, FILING, AND SCRAPING

Where large surfaces require reduction by hand, grooves may first be cut by a narrow cross-cut chisel, and the remaining surface then chipped to the depth of the grooves. The direction of chipping should be away from the edges when the latter are approached. Roughing work with the file is best done with bastard or middle-cut files, the backs of half-round files being specially suitable for removing large quantities of metal During this work full pressure should be applied, except during the return stroke, when the pressure is relieved. Care should be taken to secure a level surface, and to avoid the tendency to high places toward the centre of the work. Small quantities may be removed by the use of smooth-cut files, lightly handled. As the work proceeds, the surface of the file should be cleaned with a file brush. Where surfaces of high accuracy are required, machined or filed surfaces may be scraped. In the early stages the accuracy of the surfaces may be tested by straight-edges, but surface plates are necessary for fine work, or for large surfaces These plates are smeared with a light coating of oil, or "marking," so that high places are indicated when the plate is rubbed over the surface The coating should be omitted during the final stages of the work

ERECTION OF RECIPROCATING PUMPS

There is little in the design of the ordinary reciprocating pump which calls for special skill in erection. The order of assembly is practically self-evident from the design, and automatic alignment is facilitated by the methods which have already been discussed. Direct-coupled motors should, however, be carefully aligned with the pump shaft and gear wheels ; connecting rods, crankshafts, and bearings also require to be

accurately aligned before finally bolting up Power-driven pumps should be lined-up upon rigid foundations, and secured by adequate holding-down bolts In general, the diameters of the connecting pipes should not be less than those of the branches on the pump, and the pipework should be supported independently of the pump. Suction pipes should be as short and direct as possible, and the total suction head should not exceed that given by the makers. Air vessels, relief valves, retaining and isolating valves all require selection in accordance with the working conditions, and it is preferable that proposed arrangements of the pipework be approved by the makers before erection is commenced. Adequate drainage arrangements are required in the steam and exhaust pipes of steam-driven pumps, and precautions should be taken to see that all pipes are free from sand or grit before the pump is set to work.

CENTRIFUGAL PUMPS

Classification. Centrifugal pumps are being applied in increasing numbers to the varied purposes of industrial and municipal practice A brief classification of the principal types is as follows—

1. Low-lift and medium-lift pumps (Figs. 26 and 27), with single stage or two-stage impellers in series, and discharging into volute casings. Suitable for all general industrial purposes involving heads up to about 400 ft., and water quantities up to about 150,000 gals. per min Such pumps are extensively used for pumping to overhead tanks and reservoirs, through condenser and similar circulating systems, dock and irrigation work, and a host of similar purposes connected with the fluid supply and discharge.

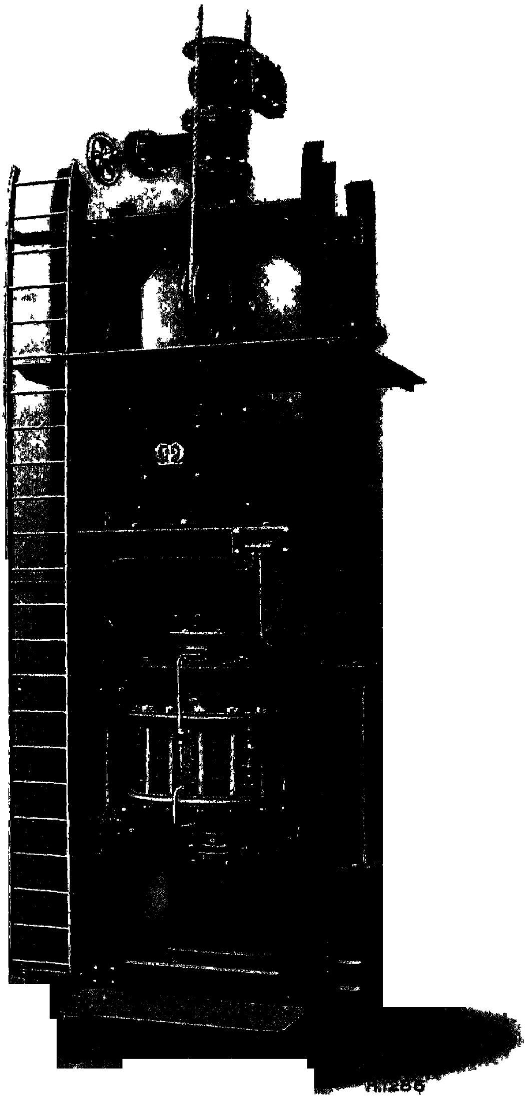
2. High-lift pumps (Fig. 28), with single- or multi-stage impellers, discharging into accurate guide

passages, and suitable for the greatest heads found in modern industrial practice High-lift pumps are commonly used for draining mines, municipal and hydraulic supply, and many similar purposes involving high pumping heads

3. Bore-hole and sinking pumps (Fig 30), consisting of multi-stage pumps and guide wheels. Specially arranged for pumping from bore holes, and for draining mines and shafts during sinking operations, respectively.

4. Centrifugal feed pumps with single- or multi-stages driven by electric motor or turbine, and specially arranged for the pumping of feed water to steam boilers

Arrangement. A wide variation in the details of design and the arrangement of the parts is apparent in the standard practice of various makers, and the processes of fitting and erection are, to an extent, dependent upon individual designs Generally, however, low-lift, medium-lift, and high-lift pumps may be arranged upon a combination bed plate for direct drive from electric motors, or they may be driven through belts, ropes, or gears. Direct-coupled sets usually incorporate a flexible coupling between the pump and motor, and the same arrangement is applicable to boiler-feed pumps, or the pump shaft may be in one with the shaft of the turbine Flexible couplings of cast iron or steel are also fitted in the case of sinking and bore-hole pumps, together with thrust bearings to support the revolving weights Sinking pumps with their driving motors and connecting pipes are accommodated in vertical frames suspended from overhead gear, which enables them to be raised or lowered as required Bore-hole pumps are driven from the surface by vertical direct-coupled motors, or by steam or internal combustion engines through bevel gears. The pump is



(*Mather & Platt*)

FIG. 30. CENTRIFUGAL "SINKING" PUMP

placed at the lower end of the bore hole, and delivers to the surface through delivery pipes suspended from the top—the driving shaft passing down the centre of the pipe through lignum-vitae bearings carried in brackets at the pipe flanges

The pipe systems of low-lift and medium-lift pumps usually incorporate foot valves and strainers at the end of the suction pipe and sluice valves in the delivery mains. For heads greater than about 300 ft., or where the pump delivers through long pipe lines into overhead reservoirs, it is advisable to add a non-return valve between the delivery flange of the pump and the sluice valve. By-pass valves round the delivery sluice and non-return valves enable the pump to be easily primed from the delivery column. Other common fittings are filling funnels with their cocks, air cocks for each stage, emptying plugs or cocks, and pressure gauges. The working parts of high-lift pumps are, in some designs, accommodated in a solid casing, with end covers and connections secured by studs and nuts in the manner of a steam engine cylinder. In other designs each stage is built as a separate unit, with end covers and connections securing the stages by means of continuous bolts and nuts The end covers also support bracket bearings, lined with white metal and ring lubricated. Low-lift and medium-lift pumps may have two bearings of a similar design with removable end covers, or they may, for small pumps, have a single external bearing with removable end cover. In some designs medium-lift pumps are provided with casings split along their horizontal centre lines to facilitate access to the internal parts

Fitting. All modern works have designed standard ranges of pumps in the various styles, and they endeavour, by means of production methods, to reduce the costs and simplify the process of manufacture.

Impellers, guide wheels, shafts, packing rings, couplings, and bearings are machined in all accessible places by special machine tools, to limit gauges and under a rigid system of inspection. The amount of fitting is, therefore, reduced to a minimum, but such fitting as remains after the machining is complete requires to be performed with special accuracy and skill By these means, interchangeability of the parts is secured, and standard spare parts may be purchased and fitted exactly in place when renewals are required. Guide passages are filed and scraped to a smooth surface, and the vanes of impellers are filed to template. When complete, the impellers are carefully balanced to ensure freedom from vibration and undue wear of bearings Keys for securing the impeller to the shaft are fitted so as to give the best possible fit, the shafts are ground and the bearing bushes scraped to an exact fit on the shaft. Thrust bearings, balancing devices, and packing rings require careful assembly and adjustment in accordance with the maker's standard clearances Studs, bolts, and nuts should have free and well-fitted threads, and should be so disposed as to secure complete metallic contact between flat faces. The fitting of external fittings and valves should enhance the appearance of the pump by the avoidance of overlapping joints, tool marks, sharp edges, and rough castings. Continuous pump casings are tested hydraulically, and completed pumps are tested in special test bays for capacity, head, and efficiency.

Some leading makers devote considerable time and expense to the testing of their pumps, either by direct volumetric measurement of the water delivered, or by measurement through the agency of calibrated notches or meters In the best makes, impellers, guide wheels, and packing rings are normally of bronze, shaft of high grade steel, and casing of cast iron or cast steel (for

high pressure) Zinc free bronze, special bronze alloys, hard lead, and other metals are sometimes used in the construction of the rotating parts—or, if necessary, of the entire pump—in special cases where it is necessary to pump corrosive or abrasive liquids Bed plates are machined on the faces for the reception of the pump and motor feet, and on the underside to facilitate erection upon a level foundation The motor feet should likewise be planed on the underside, where they are to be mounted on a combination bed plate for direct-coupling to the pump. It is most important, with such sets, that the alignment of pump and motor should be accurate When the pump and motor are both made by the same firm, the complete set may be aligned and erected prior to dispatch

This may also be done if the motor is sent, in advance, to the pump maker's works In such cases, it is customary for the pump makers to send the motor half-coupling to the motor manufacturers rough bored to an agreed diameter The motor manufacturers then fit and key the half-coupling to their motor shaft end, and, if necessary, balance the rotor and attached half-coupling. They also send to the pump makers gauges or accurate dimensions, showing the exact axial height of the motor shaft from the underside of the motor feet, so that the motor facings on the bed plate may be machined to suit When the motor and half-coupling are received from the motor manufacturers they are assembled on the combination bed plate in line with the pump Care must be taken to ensure that the two halves of the flexible coupling are exactly parallel and correctly centred This may be tested by applying a straight-edge along the sides of the adjacent half-couplings at opposite points on the periphery The clearance between the faces of the half-couplings must also be in accordance with the designer's specification,

so that the pump and motor shafts are enabled to "float" in a lengthwise direction independently of each other. When everything is correctly set, the bolts and dowel pins which fix the component parts may be fitted.

Erection. If the motor with half-coupling, and the pump, half-coupling, and combination bed plate are sent separately to site, the procedure is as before, except that the final alignment and fitting of motor-securing bolts are done on site. The dowel pins may be fitted after erection and alignment are complete and the set has had a preliminary run. As a rule, the pump is received on site as a completely assembled unit The bed plate with pump and motor (if already mounted) is then placed upon a concrete or similar foundation, varying in depth from about 1 to 5 ft in accordance with the size and type of pump and the nature of the subsoil. It is then levelled provisionally by means of the supporting wedges, and the foundation bolts grouted in. The set is then lined up accurately, and the foundation bolts tightened slightly. If the pump and motor have not previously been mounted, they may now be placed in position and carefully fixed in accordance with the procedure already outlined. In any case, the alignment of the coupling should be again checked at this point, and again after the set has been grouted in and the grouting is firmly set. A similar procedure is adopted where the pump and motor are fixed independently on foundation blocks, without the inclusion of a combination bed plate. Extended shafts with belt pulleys and pedestal bearings must be accurately in line with the pump, as in the case of the direct-coupled motor. Care must also be taken to ensure that the bases of bed plates, or of pump and motor feet, rest evenly on the foundation, so that distortion is avoided when the foundation

bolts are tightened. When belt or rope drive is adopted, the driving and driven shafts must be exactly parallel, and the pulleys in line Belt fasteners should be excluded, and the joints of the belt scarfed and cemented. Where the pump is dismantled prior to dispatch to site, the parts should be thoroughly cleaned and oiled prior to assembly The order of assembly should then be in accordance with the maker's directions, care being taken to ensure that the guide-wheel passages are disposed in the direction of rotation, and the vanes of the impellers in the opposite direction. Prior to starting, the glands should be packed with soft cotton packing served with tallow and graphite, or with a suitable oil. The glands should not be tightened unduly on the shaft, or heating and scoring may occur. The oil wells of the bearings should be cleaned, washed out with paraffin, and filled with a high grade machine oil.

Piping. The joints in suction and delivery pipes should be well made, and the suction pipe especially should be thoroughly airtight In ordinary circumstances the total suction lift, inclusive of friction, should not exceed about 15 ft Where hot liquid is to be pumped, the pump must be below the level of the source of supply, and in such cases a sluice valve should be fitted in the suction pipe. No foot valve is required, but a strainer may be fitted Foot valves and strainers are always required when the pump is required to lift the water, and these fittings should terminate a sufficient distance below the water-level to prevent the access of air when the surface of the water is disturbed by the suction of the pump. The suction piping should rise continuously to the pump, or, if this is impossible, means for evacuating the air must be provided at the highest point of the pipe. Distance pieces between the suction branch and suction pipe should be fitted so that their upper surfaces

are horizontal or rising *towards* the pump When the pump is primed from the delivery column, the suction pipe and fittings are subjected to the full pressure of the rising main, and they should, therefore, be of sufficient strength to withstand this pressure without fracture or leakage at the joints. The suction and delivery piping should be supported independently of the pump, so that undue straining of the pump flanges is avoided. During the erection of the suction piping care should be taken to see that all loose articles, e g. tools, packing pieces, etc , are removed before finally closing up, and the interiors of the pipes should be kept thoroughly clean.

SECTION XXXVI

TESTING OF STEAM ENGINES

BY

ENG LIEUT.-COM T. ALLEN, R N (S R)
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SECTION XXXVI

TESTING OF STEAM ENGINES

PART I

APPARATUS AND METHODS

Works and Site Tests. Tests of steam engines are made for the following purposes—

1. To check the performance of completed machines prior to dispatch from the maker's works.
2. To determine the performance of installations in working order on site, e g. during acceptance trials.
3. For experimental purposes.

Routine shop tests are usually carried out upon special test beds with facilities for the rapid connection of pipe lines and holding-down attachments. Test condensers, water-measuring tanks, and apparatus for the absorption of load and the measurement of power, pressure, and temperature, are also available. The same is true, to a lesser extent, in the case of experimental tests in laboratories and research departments In the case of factory tests, however, measuring appliances and instruments have usually to be applied to suit individual cases. Many of our leading engine builders—particularly in the case of high-speed engines—make shop tests a regular feature of manufacture. Such tests serve the double purpose of ascertaining that the engine is capable of the performance laid down by the designer and of demonstrating to the purchaser that the performance is in accordance with guarantees. In the case of large, slow and medium-speed engines. shop tests are more difficult to arrange, and the

expense of equipping and maintaining adequate test beds and boiler plant imposes a limit upon the size of engine which may be tested without undue addition to the cost. Makers of these engines, therefore, frequently omit the shop tests, but, in most cases, it is necessary to satisfy the purchaser by testing the engine on site under actual working conditions Certain disadvantages arise as a result of this procedure, as factory conditions do not always permit of the load being varied by the requisite amounts and maintained uniform during the periods of the test runs Variations in steam pressure and temperature also occur, and the preparation and application of the test appliances are more difficult to arrange

Test Fittings. The purpose for which an engine is built has, to a certain extent, an influence upon the fittings with which it is supplied Experimental engines, built for use in laboratories are, of course, generously equipped in this respect. Engines for industrial use, however, are sufficiently well equipped if they are fitted with thermometer pockets at the points of steam admission and exhaust, adaptors and cocks for the attachment of indicators at each end of the cylinders, indicating gear and pulleys for the drives to the indicator drums, and connections for pressure or vacuum gauges in the steam admission, intermediate, and exhaust systems. Measuring tanks and water meters for measurement of condensate, feed, and circulating water quantities are added as required together with thermometers for the measurement of the water temperatures Tachometers or revolution counters should be a permanent feature of all installations, and steam-flow meters are sometimes fitted—especially in the case of steam extraction engines Rope brakes and dynamometers for the measurement of b.h.p are common features of test bed equipment, but they are not

usually practicable with industrial plant, where the b.h.p. has to be calculated from "no-load" diagrams or from the output of electrical generators. The latter methods are also, of course, applicable on the test bed, and generators with specially calibrated instruments are often installed in the works

A brief description of some of the apparatus referred to is as follows—

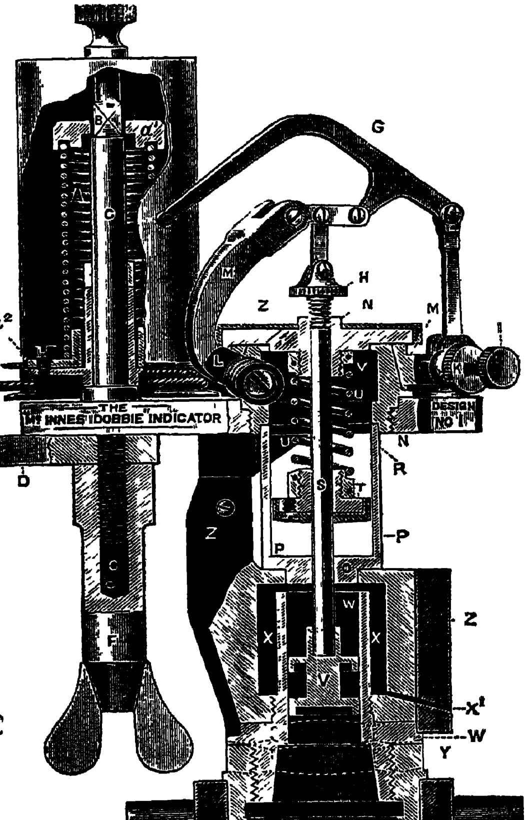
Thermometer Pocket. A small cup-shaped receptacle screwed into the cylinder or pipe and partly filled with oil or mercury for the reception of the thermometer bulb.

Indicator Connections. Usually comprising bored adaptors or bosses at ends of cylinder barrels and screwed at the outer end for reception of indicator cocks. The latter are arranged with through connections from cylinder to indicator (for recording cylinder pressures) and, alternatively, from atmosphere to indicator (for recording atmospheric pressure).

Indicator. For the measurement of i.h.p. and the checking of valve setting. An instrument designed to trace a closed diagram of the varying pressure in the cylinder—the area of the diagram representing to scale the work done on the piston per cycle. Figs 1 to 4 illustrate a type of indicator which gives very good results with steam engines This indicator is made by Messrs. Dobbie McInnes & Clyde, of Glasgow, to whom the writer is indebted for the illustrations. The notes appended to the figures explain the general features and the principle of operation of the instrument.

When indicating the engine, the indicator is attached to the indicator cock by means of the coupling nut *Y*, and the driving cord is connected to the indicating gear and adjusted so that the drum oscillates freely during the revolution of the engine. Adjustment of the cord

Fig 1



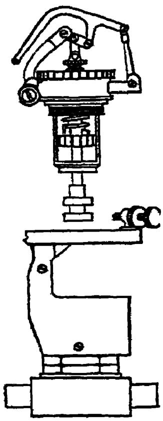
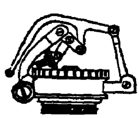


Fig. 2

Fig 3.



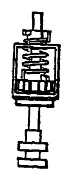


Fig 4

FIGS. 1–4. DOBBIE McINNES EXTERNAL SPRING INDICATOR

W Indicator cylinder in communication with engine cylinder
V Steel piston acted upon by varying steam pressure in engine cylinder
G Parallel motion multiplying piston travel six times at pencil point
A Spring for returning diagram drum after rotation caused by pull of cord

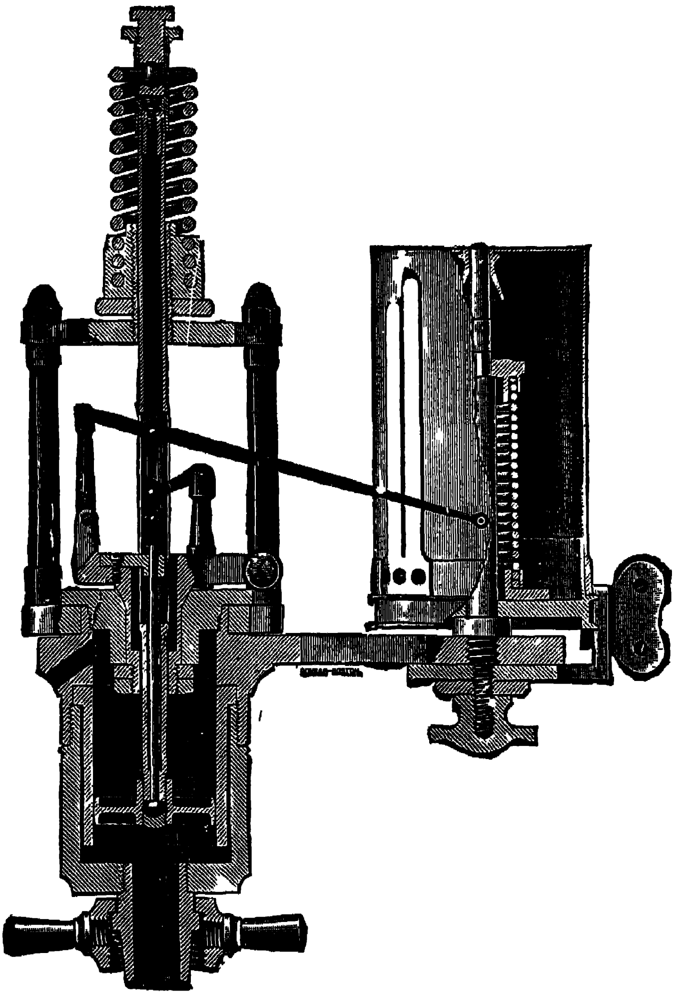
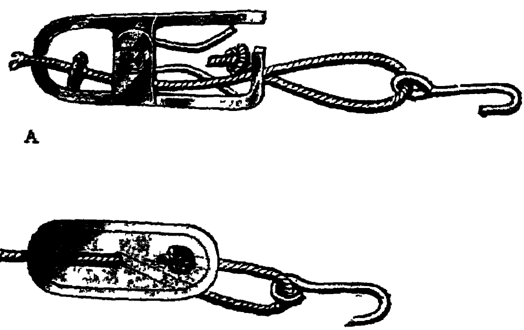


FIG 4A CROSBY EXTERNAL SPRING INDICATOR

is facilitated by the provision of adjusting devices similar to those shown in Fig 5.

The tension on the drum spring may be adjusted by the cap *a′*, so that there is a steady and sufficient reaction to the pull of the cord. The indicator is supplied with a series of pressure springs, as at *u*; each spring being specially calibrated so that 1 in of vertical



A

B

FIG 5. ADJUSTING CLIPS FOR INDICATOR CORDS

movement of the indicator pencil ensues when the indicator piston is subjected to a specified pressure, e.g. 1 in. = 80 lb. per sq. in. The springs of the indicator illustrated are external to the indicator cylinder, and are not, therefore, affected by the steam temperature. Specially prepared charts are secured to the drum by means of suitable clips, and the parallel motion is made to move by pressing upon the push *L* whenever it is desired to bring the pencil in contact with the diagram. The adjustable stop *K* provides a limit to the rotation of the parallel motion, and is of great convenience during actual tests.

Indicating Gear. An arrangement of link work driven from some reciprocating part of the engine (e.g. cross-head) and designed to transmit to the drum a reduced

copy of the motion of the piston The connection between gear and drum is made by special indicator cord. One indicator may be driven from another, and suitable rings should be fixed to the cord for disconnecting the drive when changing cords Special cord pulleys similar to those shown in Fig 6 may be fixed at suitable places to ensure a smooth drive to the drum.

A diagrammatic sketch of a form of indicating gear, devised by Messrs Belliss & Morcom for the testing of

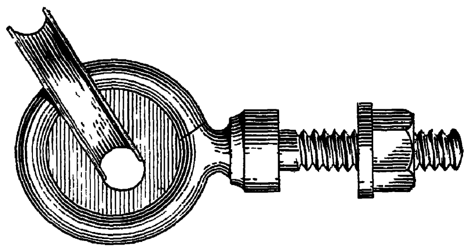


FIG 6 CORD PULLEYS FOR INDICATOR DRIVES

their high-speed engines is given in Fig 7 The instructions for setting the gear are as given below

The requirements are that the gear shall accurately reduce the motion of the piston and transmit same to the indicator drum, the latter being made to move as nearly as possible in synchronism with the former The gear consists essentially of a driving pin *A*, a link *B*, a lever *C*, a rocking shaft *D*, and a quadrant *E* The driving pin *A* is screwed into the end of the piston rod crosshead pin, and is concentric with it The link *B* is connected at its one end to the driving pin *A*, and at its other end to the lever *C*, which latter should be of such length as to allow link *B* to swing equally on either side of the vertical centre line The lever *C* should also swing equally above and below the horizontal centre line ; the link *B* being of suitable length to allow of this.

The quadrant *E* is to be so adjusted on the rocking shaft *D* that the driving cord or fair lead *F* shall always be tangent to the arc of the quadrant, and the small

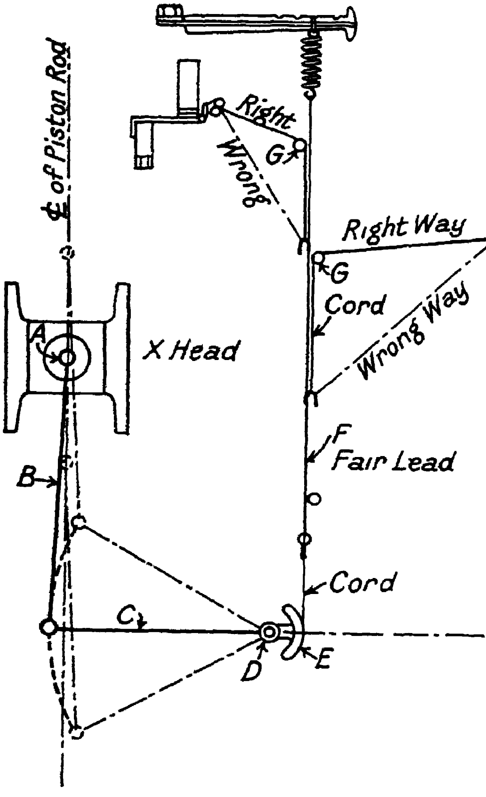


FIG 7. DIAGRAMMATIC ARRANGEMENT OF INDICATING GEAR

pin shall not foul the cord, and so increase the effective radius. The quadrant should be of the necessary radius to give an indicator diagram 2 to 2·5 in. long.

On large sets, where the fair lead *F* is used, care is to be taken that sufficient tension is maintained to avoid

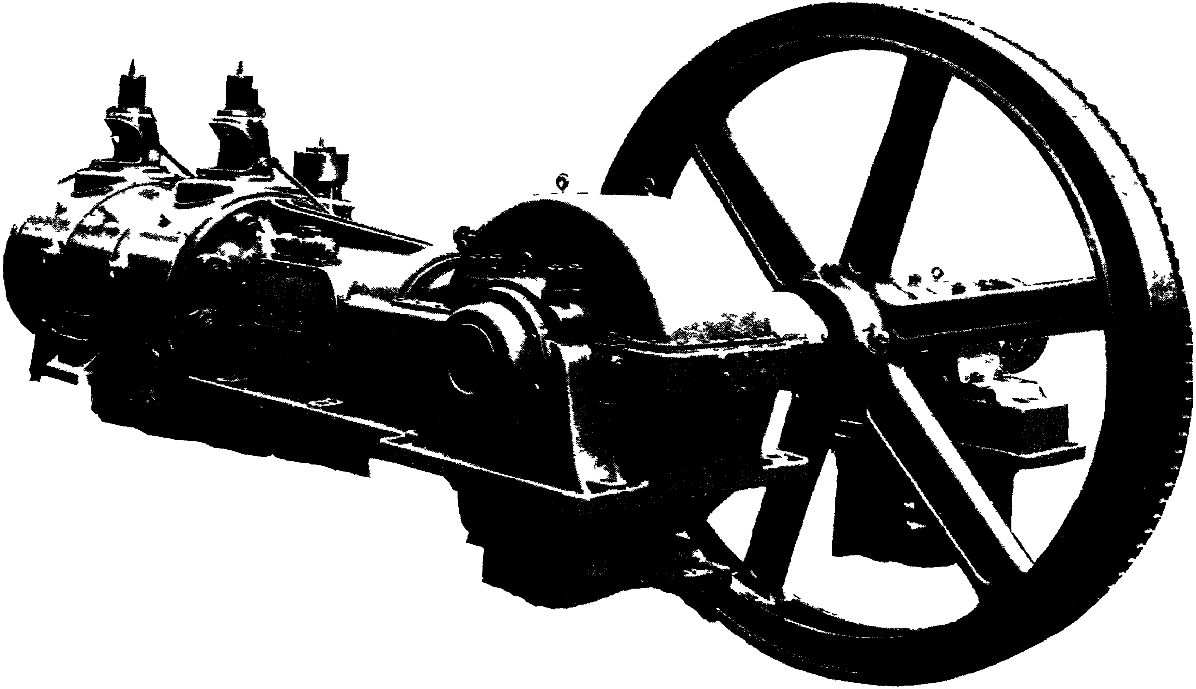


Fig 8 Horizontal Back Pressure Steam Engine
Showing Indicating Gear and Cylinder Adaptors

whipping of the cords. Also. in no case should an indicator cord be hooked on to the fair lead and allowed to make an appreciable angle with it. The cord must be constrained to move in line with the fair lead by means of a roller bracket *G* before attachment. If these instructions are not carefully followed out, an incorrect

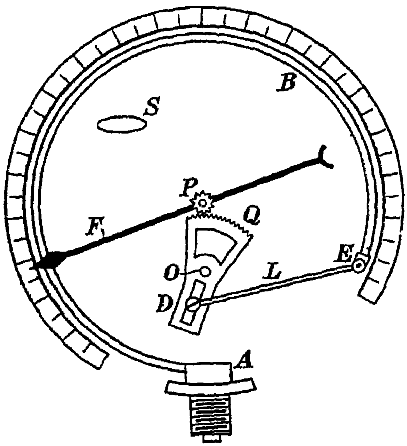


FIG. 9 PRESSURE GAUGE MECHANISM

motion is liable to be imparted to the indicator drum, resulting in a distorted diagram.

Fig 8 shows the external appearance of a type of indicating gear applied to horizontal engines. The photograph also shows the cylinder thermometer pockets and the adaptors for indicator cocks.

Pressure Gauges (Fig. 9). For measurement of initial and intermediate steam pressure Compound gauges showing positive or minus pressures (vacuum) are sometimes connected to the intermediate receivers. The gauges are usually of the Bourdon tube type with isolating cocks and syphon connecting pipe to prevent access of steam to the Bourdon tube. Recording

pressure indicators giving a record of steam pressure on a time base may also be fitted.

Mercury Thermometers should be nitrogen-filled when used for initial steam at high temperature Occasionally temperature indicators, giving a continuous record of steam temperature, are used Additional thermometers with medium or low readings are required for the temperature readings of intermediate and exhaust steam, lubricating oil, injection inlet and discharge water of jet condensers, and condensate and circulating water of surface condensers.

Barometer. For measuring the pressure of the atmosphere at the time of the test

Vacuum Gauges. (*a*) Of the dial type, similar to pressure gauges, the Bourdon tube contracting as the pressure falls below atmospheric.

(*b*) Of the mercury column type as illustrated in Fig 10 This apparatus consists of a glass tube connected at the top to the condenser through a copper pipe and isolating cock, and immersed at the lower end in a small vessel of mercury As the pressure falls below atmospheric, the mercury rises in the tube. The height of the column may be measured by the attached scale, with the zero mark adjusted to the level of mercury in the vessel. The difference between the reading of the

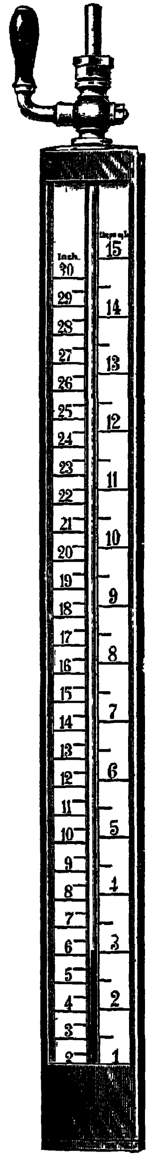


FIG 10 MERCURIAL VACUUM GAUGE
(*Budenberg Gauge Co*)

barometer and that of the mercury column represents the absolute pressure in the condenser Care should be taken to see that the mercury is not drawn into the

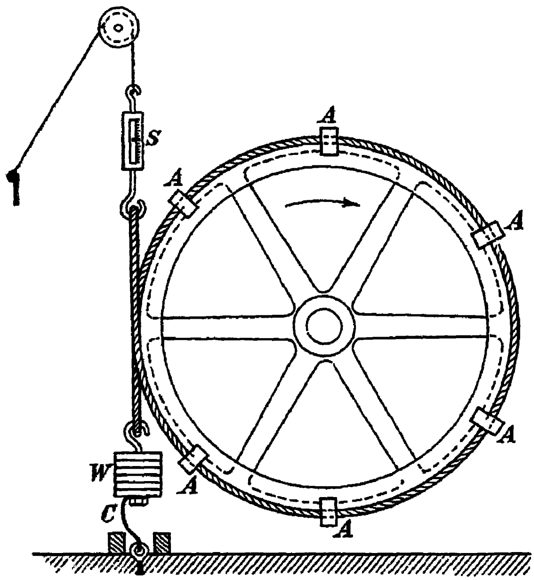


FIG 11 ROPE BRAKE

condenser by a sudden opening of the isolating cock, or any similar cause

Dynamometers. For the measurement of b h p.

(*a*) ROPE BRAKE. The use of this brake is usually confined to engines of small or moderate power and speed, tested in works or laboratories A diagram of the brake is given in Fig 11 The apparatus comprises turns of rope placed round the flywheel and connected at the top to a spring balance *S* and at the bottom to the applied weights *W*. The wooden blocks *A* are attached to the ropes so as to space and keep them in position and the loose rope *C* is fitted to prevent the

weights being carried to the top in the event of a sudden increase of friction For greater loads of longer duration it is preferable to apply the ropes to the rim of a water-cooled brake wheel, as illustrated in Fig 12

(*b*) HYDRAULIC DYNAMOMETER One form of this machine is illustrated in Figs. 13 and 14, which show sectional and photographic views of a dynamometer

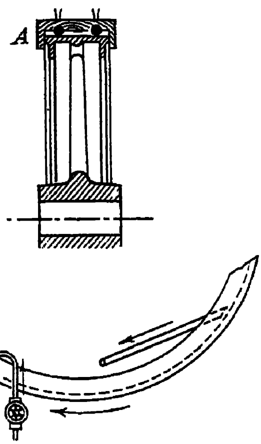


FIG 12 WATER-COOLED BRAKE WHEEL

constructed by Messrs Heenan & Froude, of Worcester The dynamometer rotor revolves inside a casing and is fixed to a shaft which is coupled directly to the engine This shaft is carried by bearings fixed in the casing—the latter being supported in trunnions, so that it is free to swivel about the same axis as the shaft. The faces of the rotor and casing are pocketed, so that energy transmitted from the engine is rapidly absorbed through the agency of water, which circulates at high velocity through the pockets Sluices, operated by an external handwheel, make it possible to regulate the load imposed by the dynamometer, and the circulating water, after

being heated in the machine passes away at a temperature regulated by the outlet valve (about 140° F) When turning moment is applied to the shaft any resistance created by the dynamometer tends to swivel the casing in its supports This tendency is resisted solely by an arm attached to the casing and connected through pin joints to a spring balance, with weights

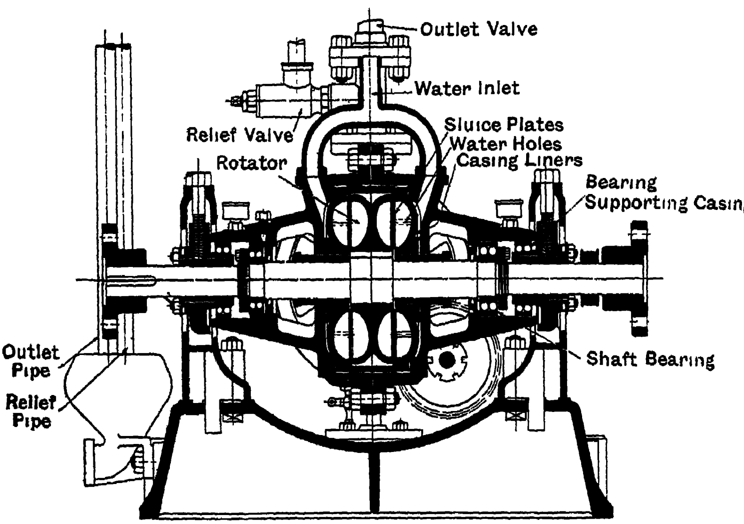


FIG. 13 SECTION OF FROUDE HYDRAULIC DYNAMOMETER

suspended so as to put the spring in tension When the dynamometer is at rest and uncoupled from the engine, the arm is horizontal and the pointer indicates zero. The dial is graduated to give a reading of lifting force at the end of the lever arm. Such dynamometers are adapted to a wide range of speed and power, and they are commonly found on works test beds and in engineering laboraorties.

(c) BY MEASURING THE OUTPUT OF ELECTRICAL GENERATORS. This method is exemplified in Part II

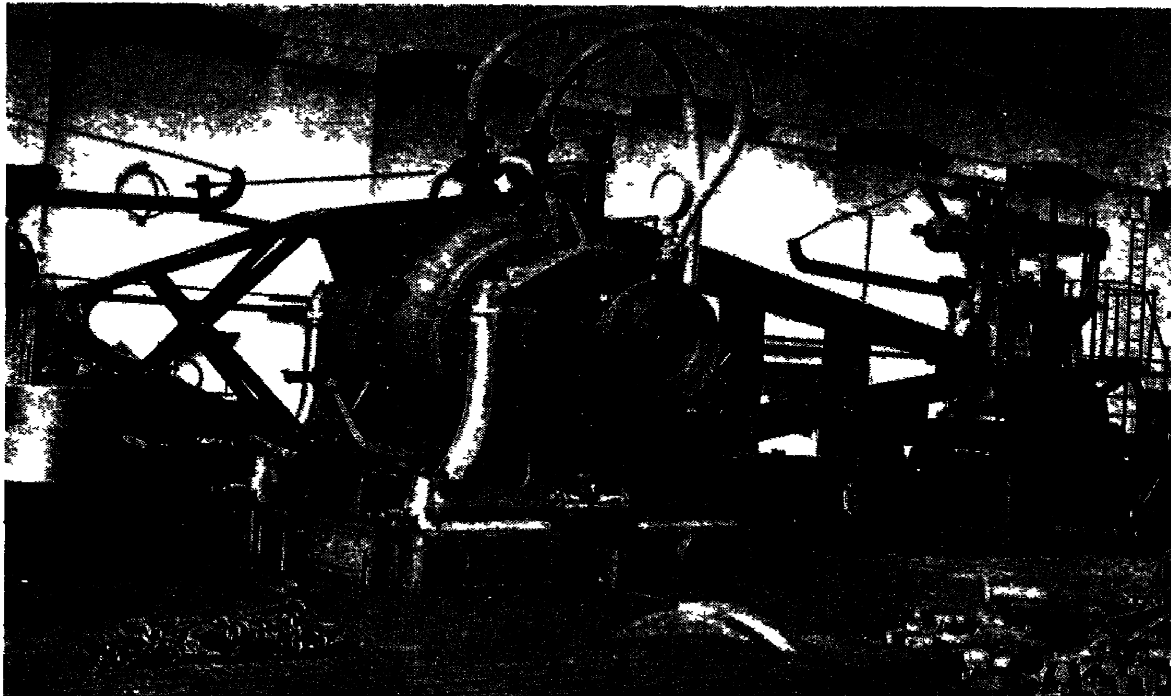


Fig 14 Froude Hydraulic Dynamometer

of this section, where reference is also made to calculations of b.h.p from "no-load" indicator diagrams.

Tachometer. For indicating the rate of revolution of the crankshaft One form of the instrument is shown in Fig. 15.

The tachometer may, with advantage, be combined with a counter for indicating the number of revolutions made by the shaft. Recording tachographs are specially useful in governor tests.

Steam-flow Meters. For indicating or recording the quantity of steam passing through steam mains These meters are of particular use in the factory tests of steam extraction and back pressure.

Engines where the working conditions are such that the whole, or part, of the steam passes out to the factory for process purposes, and measurement of the feed or condensate is not sufficient to give complete results.

Steam-flow meters of the type manufactured by Messrs. George Kent, Ltd., Luton, are illustrated in Figs. 16 and 16A. The design of these meters is based upon a law which states that the rate of flow through a constriction placed in a steam main is approximately proportional to the square root of the difference of pressure across it if the pressure and superheat of the steam are kept constant, and approximately proportional to the square root of the product of the difference of pressure and density of the steam if the pressure and superheat vary. The apparatus is made up of three parts—

1. The orifice, inserted between two flanges of the steam pipe.
2. The cooling chambers connected to the orifice by carrying bars, in which steam condenses and fills the pressure pipes and instruments with water.
3. The steam-flow recorder, operated by—

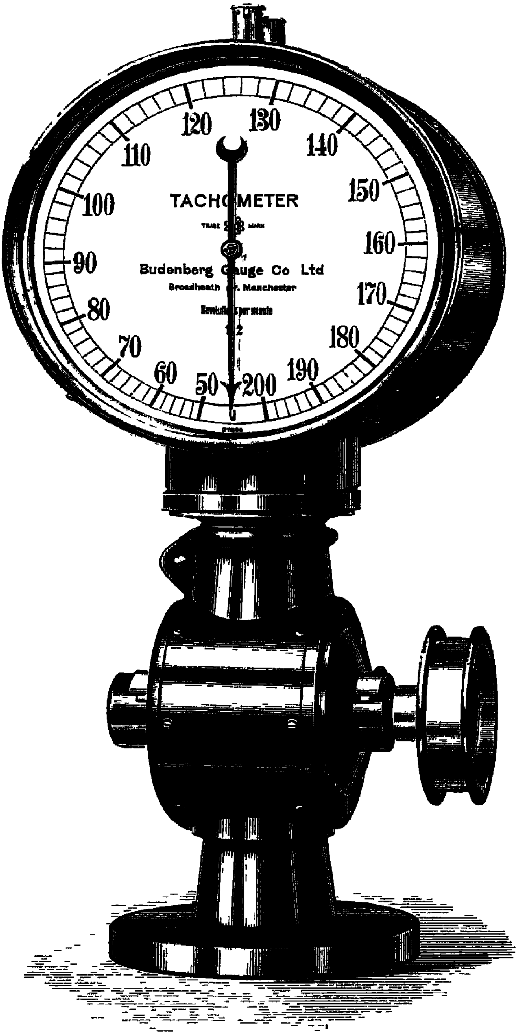


FIG 15 VERTICAL CROSS-PENDULUM TACHOMETER
(*Budenberg Gauge Co.*)

(*a*) Difference of pressure across orifice, for non-pressure corrected instruments

(*b*) Product of difference of pressure across orifice and absolute pressure of steam, for pressure-corrected instruments (absolute pressure being approximately proportional to density).

The recorder is connected to the cooling chambers by means of pressure pipes, so that the differential pressure across the orifice, created by the steam flow, exerts an influence upon the spring-controlled diaphragms of the recorder and gives to it a corresponding movement The movement of the diaphragms is transmitted, through a gland, to the external recording mechanism

The arrangement of the various parts for a meter of the non-pressure corrected type, suitable for constant pressures, is shown in Fig 16 The meter shown in Fig. 16A has additional mechanism which automatically corrects for variations in the steam pressure Orifices are calibrated for a given steam "quality," and correction factors determined by the makers for various conditions of superheat or dryness fraction The details of the instrument may be seen in Fig 16A It will be noted that the steam flow is recorded, to a time base, upon a diagram attached to a drum which is rotated by clockwork. Direct-reading scales, showing the momentary pressure and quantity of steam, are also provided and, if desired, the instruments may be arranged to record by counter as well as by diagram

Special damping valves are advisable in the case of pulsating flows such as those experienced with steam-engines, and information regarding the character of the pulsations should be furnished in accordance with the maker's requirements so that the probable accuracy of the readings may be stated With reciprocating engines, also, the orifice carrier should be placed as far from the engine as possible, so as to utilize the

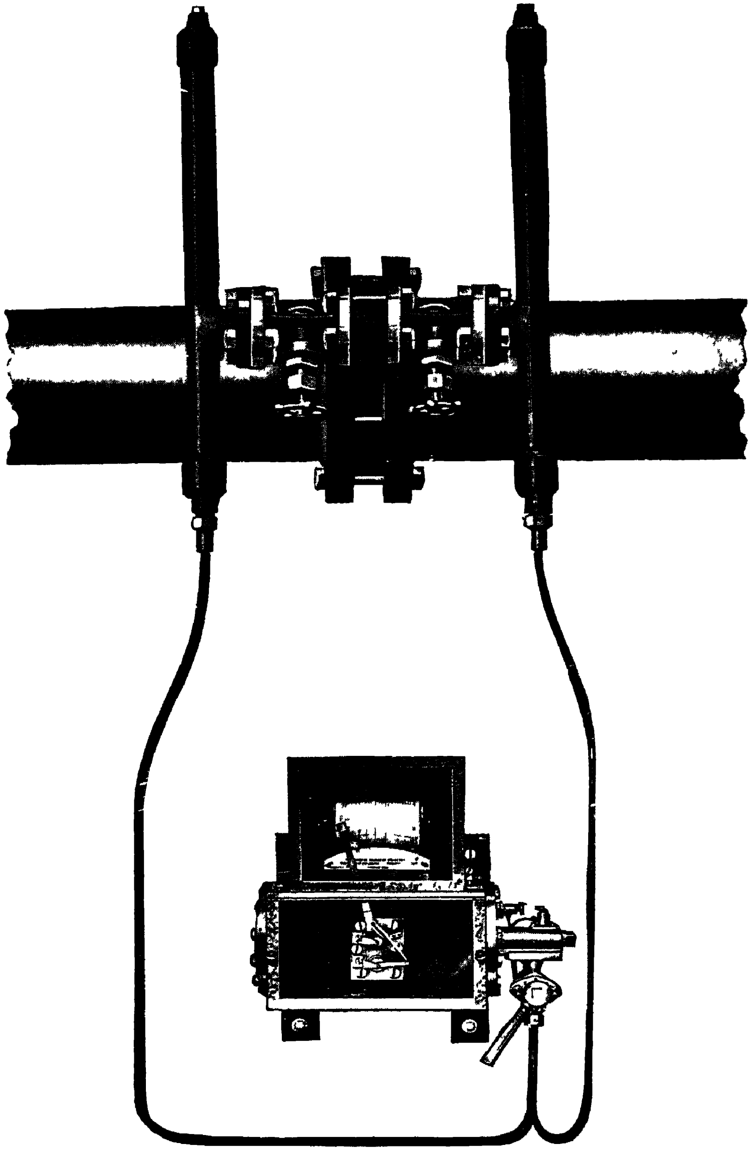


FIG 16 ARRANGEMENT OF "KENT" NON-PRESSURE CORRECTED STEAM-FLOW RECORDER

"capacity" effect of the steam main. Small rotary meters are made by Messrs. Kent for metering the flow through small steam mains.

Water Meters. Large water quantities may be measured by passing the water over notches, calibrated in accordance with well-established hydraulic

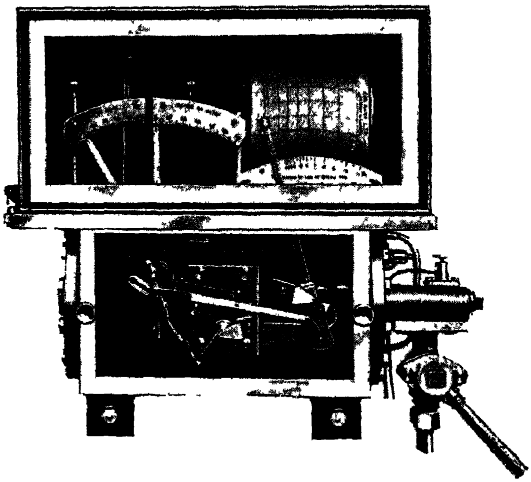


FIG. 16A. "KENT" PRESSURE CORRECTED DIAGRAM STEAM-FLOW RECORDER

formulae, or by means of Venturi tubes and meters A meter of this type, made by Messrs. George Kent, Ltd., Luton, is shown in Fig. 17 Standard meters employing notches or displacement pistons are available from the makers of water-measuring apparatus. Feed water meters or recorders are frequently fitted as permanent items of boiler installations—a good example of the type being the recorder made by the Lea Recorder Co. This apparatus combines a collecting tank and "V" notch with suitable recording mechanism, and is available, in portable form for test

purposes, or in a form suitable for permanent installation The recorder is also used for measuring the condensed steam from surface condensers, and a feature of the apparatus is the compensating device, which gives an automatic correction for variation of water density with temperature.

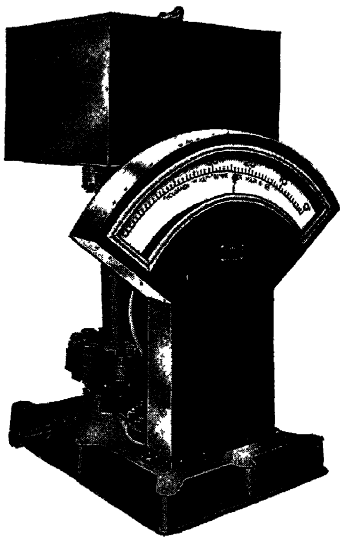


FIG 17 "KENT" VENTURI METER

Water-measuring Tanks. Special tanks are used during the tests for the determination of the steam consumption. Fig 18 is a diagrammatic sketch of an arrangement which is suitable for measurement of the boiler feed. The feed water is supplied, alternately, to the two divisions of the upper tank *A*, through a flexible pipe at the top, or through a pipe with branch connections and valves to each division. The capacities of these divisions, to the level of the overflow pipes *B*, are determined previously, by pouring in weighed quantities of water. Cocks *C*, at the bottom of each division,

enable one side to be emptied into the feed tank *S*, while the other side is filling.

A gauge as at *H* is fixed, so that the water in the feed tank, at the end of the test, may be adjusted to the same level as at the commencement. By observing the number of divisions emptied into the feed tank

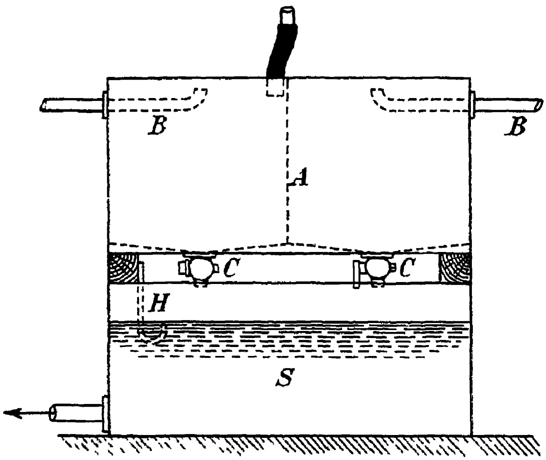


FIG. 18. WATER MEASURING TANKS

during the period of the test, the quantity of feed water pumped into the boilers (and passed as steam to the engine) may be determined. Similarly, records of the rate of feed may be made by taking observations of the discharge of individual divisions

Similar tanks may be used when the consumption is determined by measurement of the condensate pumped from surface condensers Alternatively, tanks supported on accurate weighing machines may be used, and such tanks are usually found on works test beds

During the course of steam engine tests, various accessory instruments and appliances are required, e.g. stop-watches and chronometers, for timing speeds of

revolution and duration of test runs, hand tachometers or counters, for indicating speeds of pumps and shafts, planimeters for evaluating diagrams, and the usual spanners and small tools.

Examples of the calculations connected with the use of the above instruments are given in Section II. It should be noted that serious errors may arise from the use of unsuitable instruments, or of apparatus which is imperfectly adjusted or arranged. In commercial tests, it is usually sufficient to check the indicator springs, thermometers, tachometers, meters and gauges, at the time of the test; but for experimental work, and for tests expected to yield a high degree of accuracy, the greatest care is necessary in the selection and arrangement of test apparatus. Valuable information on this subject is given in the report of the Heat Engines Trials Committee referred to in Section II.

Precautions During Tests. The following notes indicate the chief points requiring attention during steam-engine tests—

1. The motion of the indicator drum should represent exactly the motion of the piston. Indicators should be cleaned and oiled, and the parallel motions made to work freely and without play. Indicator cocks require blowing through before attachment of the indicators, and the driving cord should be taut and adjusted so that the drum does not come against the stops at the ends of the travel. The strength of the indicator spring should give the maximum size of diagram, consistent with steadiness of outline and freedom from contact with the vertical stops

2. The plant should be run for a sufficient period prior to the trial, to ensure the attainment of steady working conditions.

3. The pipe connection between condenser and vacuum gauge should be kept free of water.

4. Pressure gauges, thermometers, and indicator springs are preferably calibrated for the conditions under which they are used, but their accuracy may be checked by the makers, or in a standardizing laboratory, so as to establish any necessary corrections. Tachometers may be checked against the counted speed of the engine. Electrical measuring instruments also require careful checking, and it is desirable that they should be duplicated.

5. Separate indicators should be fitted close to each end of the cylinder The error caused by using a single indicator with pipe connections to both ends of the cylinder of a high-speed engine, is illustrated in Fig. 19.

6. During tests at specified load, every endeavour should be made to maintain uniform conditions of steam pressure, superheat, vacuum and load.

Cards from the indicators should be taken as nearly simultaneously as possible. The times at which readings of the water tanks and electric meters are taken should coincide exactly.

7. Where the boiler feed is measured, the rate of steaming and the water-level should be kept as uniform as possible, and it is desirable to isolate boilers for the sole purpose of the test. All other connections to the steam pipe should be blanked off, and the pipe joints and piston rod glands should be steamtight. Drainage from steam jackets, traps, and heaters may be collected and weighed separately, as required in individual cases.

8. Surface condensers should be tested, before and after the trial, to ascertain that there is no leakage of circulating water into the steam space. This may be done by observing the condensate discharge outlet, when steam is shut off the engine and the circulating water is turned on.

Types of Steam Engines Tested. These may be classified, broadly, into three divisions—

1. Condensing engines, in which the whole of the steam is condensed after passing through the cylinders.

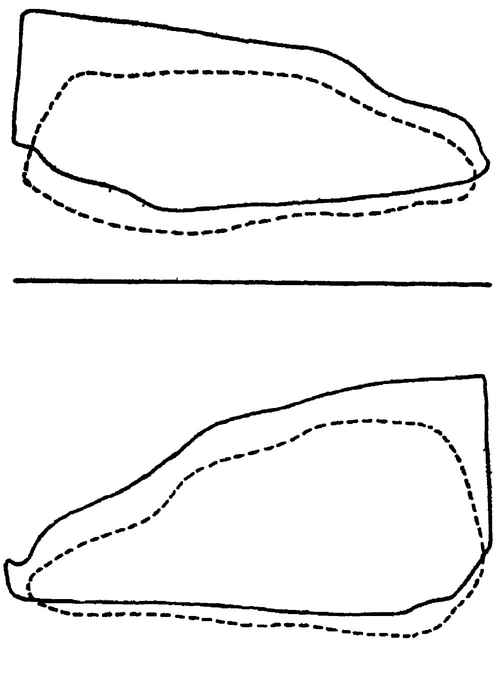


FIG 19. ERRORS OF INDICATOR DIAGRAMS
(see opposite page)

2. Back-pressure engines, in which none of the steam is condensed but is exhausted to process machinery, or to atmosphere

3. Steam extraction engines, in which part of the steam is condensed and part is exhausted to process machinery.

The classification may be extended to include the

following types of engines, all of which are built for industrial purposes.

(*a*) Slow-speed horizontal or vertical engines with slide, Corliss, or drop valves; condensing or non-condensing.

(*b*) Single-cylinder, medium-speed, condensing Uniflow engines with drop valves.

(*c*) Medium-speed, back-pressure, and extraction engines with drop valves.

(*d*) High-speed or quick-revolution engines with piston slide valves—condensing, back-pressure, or extraction types.

Where jet condensers are fitted, reciprocating pumps may remove both air and water, or there may be separate centrifugal extraction pumps for the water and ejectors for the air. In the case of surface condensers, reciprocating pumps may be used for the air and condensed steam, or there may be a combination of centrifugal condensate pump and ejector air pump. In both cases circulating water is supplied under pressure from an outside source, or pumped by reciprocating or centrifugal circulating pumps.

General Outline of Test Methods. The steam exhausted from the cylinders of jet condensing engines mixes with the injection water and cannot be collected and weighed separately for the determination of the steam consumption. Works tests of these engines are, therefore, usually carried out by condensing the steam in independent surface condensers. The performance of the jet condenser may be tested separately.

Alternatively, the consumption of the engine, with its own condensing plant, may be ascertained by measurement of the boiler feed, and this method is suitable either in the shop or on site. Surface condensing installations are, of course, tested by discharging the condensate to calibrated measuring tanks.

Similarly, the steam exhausted or extracted from back-pressure and steam extraction engines may be measured in the surface condensers available on the test bed, the steam being throttled to reproduce the desired working conditions Site tests of these engines are, however, more difficult to arrange, although the steam passing to the H P. cylinder may be measured by weighing the feed water. Where it is not possible to condense the extracted steam, the quantity passing through the extraction mains may be measured by means of steam-flow meters. The difference between the steam passed to the H.P. cylinder and that extracted through the process main is the quantity used in the L.P. cylinder—due allowance being made for drainage delivered by the steam traps. A check on the L.P. steam quantity is possible when the steam is finally condensed in a surface condenser.

Conduct of Tests. In the case of routine tests in maker's works, suitable instruments, fittings and data sheets are always ready for use. This is not the case in industrial tests, and it is advisable to make everything ready before the test is timed to commence. Indicators should be prepared and satisfactory drives arranged Oil should be placed in thermometer pockets, gauges and thermometers placed in position, and apparatus such as weighing machines, tachometers, test cocks and fittings inspected, and certified to be in proper working order. Preliminary indicator cards may be taken so that faults in valve setting—likely to lead to increased consumption or erratic working—may be rectified in advance. The cylinder constants may also be worked out so that trial calculations of i.h.p may be quickly made during the test. It is advisable that spare indicator cards and rings should be available, and also, where possible, a spare indicator.

The log sheets of individual observers may be

restricted to their particular observations, but the central log sheet should be kept up-to-date with all readings, calculations and remarks connected with the test. A signalling device between the water-measuring tanks and the electric meters is of service in synchronizing the readings At the commencement of the test, stop-watches should be synchronized with the time-recording elements of pressure, temperature and steam-flow recorders. Indicator cards and readings should then be taken at regular intervals determined by the engineer in charge, special observers being allocated to the measuring tanks and meters The barometric pressure should be noted at intervals and indicator cards worked out periodically, so that uniform load may be maintained and faults developing in the valve gear, indicators and drives. corrected. A graphic log of the observations is of assistance in maintaining uniform conditions generally Should deviations from the normal occur, a note of the facts and time of occurrence should be made in the "remarks" column of the log sheet Indicator cards and log sheets taken during the test should be marked with the time at which they are taken, but it is not essential to mark *all* the cards with data regarding spring pressures, location and end of cylinder, etc. One complete notation should, however, be made at the commencement of the trial and at the time of any change of indicators or springs The duration of specified test runs varies in accordance with the requirements of the purchaser ; some tests requiring only a short run at each load, and others extending to 24 hours or more At the conclusion of a run at any given load, the load should be changed gradually, and observations recommenced after time has been allowed to permit of the resumption of steady conditions When the test is finally completed, the indicators should be dismantled and cleaned, and the springs

removed and labelled with their appropriate positions on the cylinders Thermometers, gauges and other instruments which it is desired to check, should also be cleaned and labelled prior to dispatch. The log sheets may then be completed and all cards collected, in readiness for the calculation of results.

PART II

CALCULATIONS AND RESULTS (General)*

Indicated Horse Power. The i.h.p developed on one side of the piston is given by the formula—

$$\text{i h p} = \frac{p_m LAN}{33000} = p_m C$$

where p_m = Mean effective pressure (lb per sq. in.)
L = Length of stroke (ft)
A = Area of cylinder less area of rod (if any) (sq. in.)
N = Rev per min of crankshaft
C = Constant $= \dfrac{LAN}{33000}$

The mean value of N may be derived by dividing the total revolutions recorded by the counter, by the number of minutes taken during the test If a revolution counter is not fitted and readings of a tachometer only are available, the mean of these readings may be taken.

The gross area of the cylinder should be calculated from the diameter as gauged at the time of the test, and the net area A is the gross area, less the area of the piston or tail rod.

* The numerical examples in this section are representative of general methods, and are not necessarily extracts from specific test logs

Taking, as an example, a 26 in. diameter cylinder with a 5 in. diameter piston rod and a 4½ in. diameter tail rod—

End of Cylinder	Front	Back
	Sq In.	Sq. In
Gross area of 26 in diameter cylinder	530 93	530 93
Deduct area of rod .	19 64	15 9
Net area . . .	511 29	515 03

Engineers frequently take the mean of these areas. A_1, for substitution in the formula i.h p. $= \frac{p_{m1}\ L_1 A_1 N}{33000}$. The value of p_{m1} is the average of the m.e p.'s on the two sides of the piston, and that of L_1 twice the length of the stroke. In this case i.h p. $= \frac{p_{m1}\ A_1 V}{33000} = p_{m1} C_1$

where $V = L_1 N =$ mean piston speed (ft per min)

and $C_1 = \frac{A_1 V}{33000}$

Expansion of Cylinder. The diameters of cylinders are preferably gauged hot, but as this is not usually possible, approximate corrections are sometimes made to allow for the increased diameter due to expansion. The calculation may be illustrated in the case of a Uniflow engine having the following cylinder dimensions—

Gauged diameter of each cylinder end at 60° F., 26 in.

Gauged diameter of cylinder centre at 60° F., 26·0755 in.

Mean temperature in pockets at cylinder ends during test, 389·0° F.

Mean temperature in pocket at cylinder centre during test, 126·0° F.

One formula (Hutte) for approximating to the cylinder diameter after expansion during a temperature rise of t° C. (from t_1 to t_2) is—

$$D = (1 + at + bt^2)d.$$

Where D = Diameter at temperature t_2

d = ,, ,, ,, t_1

t = Temperature rise, degree C.

a = ·000009794 } for cast iron
b = ·00000000566 }

In the example, the formula gives the following results—

Final diameter D at cylinder ends

$$= 1{\cdot}002 \times 26 = 26{\cdot}052 \text{ in}$$

Final diameter D at cylinder centre

$$= 1{\cdot}00037 \times 26{\cdot}0755 = 26{\cdot}0852 \text{ in}$$

Gross cylinder area:

at ends	=	533·06 sq in.
at centre	=	534 42 ,,
mean	=	533·74 ,,

Mean area of piston and tail rods (5 in diameter)

= 19·63 sq in

Net cylinder area (A or A_1) = 514·11 sq in

It should be noted that the difficulty of ascertaining the correct mean metal temperature and the true coefficients of expansion makes it necessary to employ empirical formulae for the calculation of increased cylinder diameter, and the results are not, therefore, accurate in all cases. Taking, in the example, a mean

value $N = 135{\cdot}82$ rev per min. and a stroke $L = 2$ ft 9 in., the constant for one end of the cylinder,

$$C = \frac{LAN}{33000}$$

$$= \frac{2{\cdot}75 \times 514{\cdot}11 \times 135{\cdot}82}{33000} = 5{\cdot}82$$

Tabulation. Calculations such as these are simplified if arranged in tabular form, as in the following example for a horizontal compound engine—

Stroke $L = 3$ ft. 0 in. Mean speed $N = 137$ r p m
Mean piston speed $V = 2LN = 822$ ft per min.
Initial steam pressure $P_1 = 150$ lb per sq. in gauge.
Intermediate pressure $P_2 = 20$ lb per sq in gauge
Vacuum $= 27$ in. $(Hg) = -13{\cdot}5$ lb per sq in.

Cylinder		Bore	Gross Area	Rods		Net Area A	Const C
				Dia	Area		
H P	F	In 27	Sq In 572 6	In 6	Sq In 28 3	Sq In 544 3	Sq In 6 78
	B	27	572 6	5	19 6	553 0	6 9
L P	F	40	1256·6	6	28 3	1228·3	15 275
	B	40	1256 6	6	28 3	1228 3	15 275

The calculation of cylinder constants is of great convenience for the purpose of test work and preliminary design. By their use it is only necessary to multiply by the m.e p. to determine the i h p. developed under given conditions.

Planimeter Calculations. Large numbers of indicator

diagrams are most easily evaluated by the use of the planimeter—an instrument illustrated in Fig. 20. When using this instrument, the diagram is pinned to a flat board and the sliding points on the beam adjusted to the length of the diagram The planimeter is then placed upon the board, the tracing pointer brought into contact with a marked point on the diagram and the weighted point pressed into the board at a convenient place outside The tracing point is then passed once round the diagram in a clockwise direction and the readings of the revolving scale noted at the beginning and end of the traverse The mean height of the diagram is obtained by dividing the difference of these readings by the constant of the instrument.

The m e p is then equal to the mean height multiplied by the calibration of the indicator spring. Taking the example of the Uniflow engine, the calculations from a test log sheet may be arranged as follows—

Time	Card No	Speed	Planimeter Reading	
			Front	Back
9 0	1	136	152	153
9 15	2	136	151	150
9 30	3	135 2	153	151
9 45	4	136 1	152	150
Mean		135 82	152	151
Mean height = $\dfrac{\text{Planimeter reading}}{\text{Constant (4)}}$		=	38	3775
Calibration of indicator spring 1″		=	80 lb per sq in	80 lb per sq in
Mean effective pressure		=	30 4 lb per sq in	30 2 lb per sq in
Cylinder constant		=	5 82	5 82
Mean i h p		=	177	176
Total mean i h p during test		=	353	

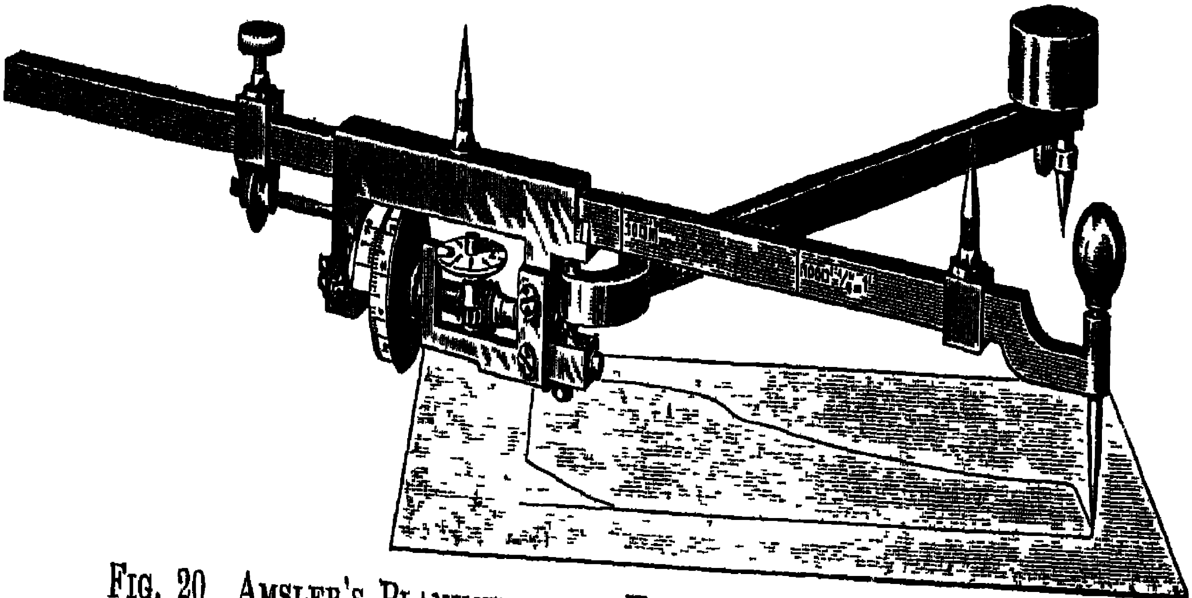


FIG. 20 AMSLER'S PLANIMETER FOR EVALUATING INDICATOR DIAGRAMS

(*Budenberg Gauge Co, Ltd*)

If the indicator springs are tested at the time of the test, any necessary correction may be applied to the above calculation.

Steam Consumption. Assuming the whole of the condensate to be pumped alternately into two measuring tanks, the log of the tank readings may be as follows—

TANK NO

1			2		
Time	State	Temp.	Time	State	Temp.
9.0 9.10 9 21 9.32	Empty Full Empty Full	102 103 101 102	Empty Full Empty Full	9 10 9 21 9 32 9 43	103 101 102 102
Two tanks in 21 min.			Two tanks in 22 min		

CALIBRATION OF TANKS

Tank No	1		2	
State	Empty	Full	Empty	Full
Weight (lb)	92	907	90	906
Net weight (lb)	815		816	

Total water entering tank No 1 = 2 × 815 = 1630 lb in 21 min

„ „ „ „ No. 2 = 2 × 816 = 1632 lb in 22 „

Total condensate = 3262 lb in 43 „

= 4560 lb. in 1 hr at 102° F mean temperature.

Assuming that the tanks were calibrated by pouring in weighed quantities of water at 62° F. temperature, a correction may be applied to allow for the higher temperature of the water during the test.

The density of water at various condensate temperatures is as follows—

Temperature Deg F.	Density Lb per cub ft
40	62 408
62	62 321
82	62·15
102	61 92
122	61·63

The corrected weight of water measured during the test at 102° F is therefore

$$\frac{61{\cdot}92 \times 4560}{62{\cdot}321} = 4525 \text{ lb.}$$

The steam consumption of the engine in lb. per i.h.p per hr. is given by

$$\frac{\text{Total weight of condensate per hr}}{\text{i.h.p.}}$$

$$= \frac{4525}{353} = 12{\cdot}82 \text{ lb. per i h.p. per hr.}$$

The steam consumption of such an engine is often guaranteed in the following form—

Initial steam pressure, 160 lb. per sq in gauge

Initial steam temperature, 471° F (100° F. superheat)

Vacuum, 28 in *Hg*. (30 in. bar.)

	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{4}{4}$	$\frac{5}{4}$
Load, i.h p. =	200	300	400	500
Steam consumption, lb. per i.h.p. per hr. = C =	11·5	11·2	11 0	11·3

The above figures are subject to the usual "tolerance" of 5 per cent

Assuming readings from the test log sheet, as given below—

Time	Steam				Vacuum	
	Pressure	Pocket Temp.				
		F	B.	Exh	Condenser	Exh. Flange
9 0 9 15 9.30 9 45	158 160 159 159	394 388 392 386	386 387 390 389	128 126 126 124	27·8 27 4 27 7 27 5	27 0 26 5 27 0 26 5
*Mean	159	390	388	126	27 6	26 75
	Mean	389				

It will be seen that the mean readings of steam pressure, temperature and vacuum are different from those upon which the guarantees are based. Small differences of initial steam pressure may be neglected, but the influence of initial temperature and of vacuum upon the steam consumption is important and must be taken into account. The necessary correction factors may be agreed, in advance, between the makers and the purchaser. For the example chosen, the corrections for initial steam temperature may take the form of a curve similar to that shown in Fig 21

In the example the mean temperature during the test was 389° F., as against a temperature of 471° F. specified in the guarantee. The correction curve shows that the ascertained steam consumption (12·82

* Any corrections derived from tests of gauges or thermometers may be applied at this point

lb. per i.h.p. per hr.) should be corrected by the factor

$$\frac{\cdot 86 \text{ (at } 471° \text{ F.)}}{\cdot 97 \text{ (at } 389° \text{ F.)}} = \cdot 89$$

The test consumption, corrected for initial steam temperature is, therefore, $12{\cdot}82 \times \cdot 89 = 11{\cdot}22$ lb per i.h.p. per hr.

For engines of the type considered in the example, the

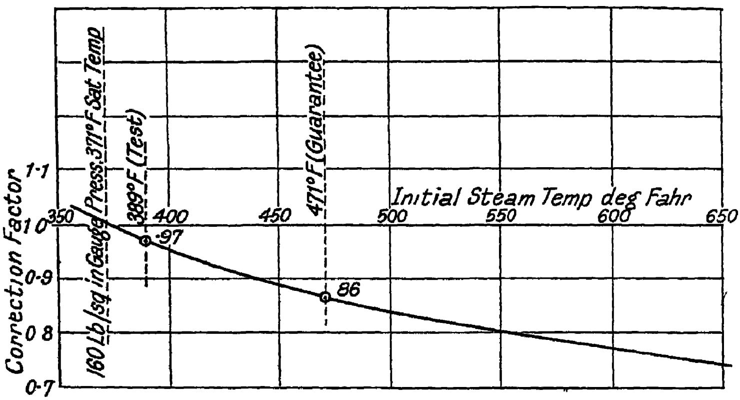


FIG. 21. INITIAL TEMPERATURE CORRECTION CURVE

steam consumption varies ± 2·5 per cent per in. fall or rise of vacuum. The average vacuum during the test was 27·6 in. with a barometer reading of 30·1 in., i.e. 27·5 in. at 30 in. barometer. As the guaranteed consumptions were specified for 28 in vacuum, the steam consumption should be further corrected by $\frac{1}{2} \times 2{\cdot}5$ per cent = 1·3 per cent (i.e. by the factor ·987). This gives a final steam consumption of

$$11{\cdot}22 \times \cdot 987 = 11{\cdot}1 \text{ lb. per i.h p. per hr.}$$

The guaranteed consumptions are plotted in Fig. 22. At the mean test load of 353 i.h.p. the curve shows a consumption of 11·02 lb. per i h.p. per hr., and at this

load, therefore, the performance of the engine is within 1 per cent of its guarantee

The observations given in the foregoing example represent short extracts from log sheets of the type taken at steam trials Actually, the log sheets would be extended to cover the whole period occupied by the tests.

Separate sheets may be used, if necessary, for each load run. The corrections for cylinder bore, water density, indicator springs, gauges, and thermometers are often omitted from ordinary industrial tests, but the

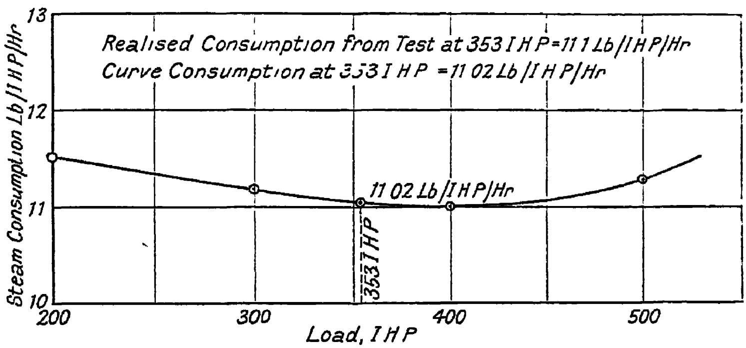


FIG 22 GUARANTEED STEAM CONSUMPTION CURVE

utmost precautions are necessary if results of scientific value are required Simple variations of the methods and calculations may be necessary to suit individual cases, e.g. where condensate, drainage, or leakage from jackets, traps, pumps, etc., is to be taken into account Calculations from tests made by measurement of boiler feed water are, generally, similar to those described

B.H.P. AND MECHANICAL EFFICIENCY

(*a*) **By Calculation from "No-load" Work.** Indicator diagrams are taken from the engine when running "light," i.e. without external load During the indication of the engine the conditions of steam-pressure,

vacuum, and engine speed should be similar to those during the main tests, and every precaution should be taken to secure good diagrams. The average i.h.p calculated from the diagrams represents the power developed merely to keep the engine in motion at the specified speed, i.e. to overcome frictional resistances The "friction load" has been shown by leading authorities to be practically constant at all loads * Assuming, in the same example as before, that the mean power shown by the "no-load" cards F = 30 i.h p. The b.h p , mechanical efficiency, and steam consumption per b h p. per hr. may be calculated as follows—

		$\frac{1}{2}$	$\frac{3}{4}$	$\frac{4}{4}$	$\frac{5}{4}$
Load, i h p	=	200	300	400	500
Subtract F = 30 i h p	=	30	30	30	30
. b h p	=	170	270	370	470
Mech. effcy. % $= \dfrac{\text{b h p} \times 100}{\text{i h p}}$	=	85	90	92 5	94
C = lb. per i h p. per hr	=	11 5	11 2	11·0	11 3
Then Q = lb per hr $= C \times$ i h p	=	2300	3360	4400	5670
and C_1 = lb. per b h p. per hr $= \dfrac{Q}{\text{b h p}}$	=	13 5	12 45	11 9	12 05

Q = total steam in lb per hr. C_1 = steam consumption in lb per b h.p. per hr Values of i h p. and C from earlier table.

(*b*) **By Calculation from the Measured Output of an Electric Generator.** In general, the principle observed is to measure the output of the generator by means of watt-hour meters over the time period of the test and thus to obtain the average load on the generator. In the case of alternators the power factor should correspond—or should be adjusted, if possible—with that specified in the guarantees. For d.c. generators,

* Dr Thurston, Prof. Ripper and others Calculations from "no-load" diagrams—whilst being the only practicable method in many "site" tests—are somewhat unreliable and, wherever possible, method (*b*) or (*c*) should be adopted

alternative readings of voltage and current may be observed every few minutes and used for the calculation of the load.

Assuming, in the example, a series of runs of 2·5 hr. duration at each load, giving the following readings—

Load =	½	¾	4/4	5/4		
i h p =	200	300	400	500	(1)	
Water tanks, lb =	5750	8400	11,000	14,150	(2)	
Watt-hr meters, units =	288	460	630	785	(3)	
Then mean load, kw =	115	184	252	314	(4)	$= \dfrac{(3)}{2\cdot5\text{ hr}}$
Steam C_2, lb. per kw per hr. =	20·0	18·3	17·5	18·0	(5)	$= \dfrac{(2)}{2\cdot5\text{ hr} \times (4)}$

Curves showing the generator efficiency are usually plotted by the generator makers from observations taken on their test beds, and for commercial tests these curves may be taken as correct. Assuming the curve of the generator to be similar to that shown in Fig. 23, the following values of the generator efficiency may be abstracted—

	½	¾	4/4	5/4		
Load, i h p =	200	300	400	500	(1)	earlier table
Load, kw =	115	184	252	314	(4)	earlier table
Generator effcy % =	91	91·5	91·5	89·5	(6)	from curve
b h p =	170	270	370	470	(7)	$= \dfrac{(4)}{746 \times (6)}$
Friction load F =	30	30	30	30	(8)	= i h p − b h p
Mech effcy % =	85	90	92·5	94	(9)	$= \dfrac{\text{b h p} \times 100}{\text{i h p}}$

If readings of voltage and current are taken to determine the output of d c generators, the average b h.p. of the engine may be calculated from the formula—

$$\text{b h p} = \frac{E \times I \times 100}{746 \times \eta}$$

where E = Mean volts during test

I = Mean amperes during test

η = Generator efficiency per cent

For experimental and other tests requiring extreme accuracy it is necessary to employ great care in the selection and arrangement of electric meters and indicating instruments. It is not possible, within the scope of this section, to treat in detail with the many different arrangements, but those interested will find valuable information in Appendix VIII of the *Heat Engines*

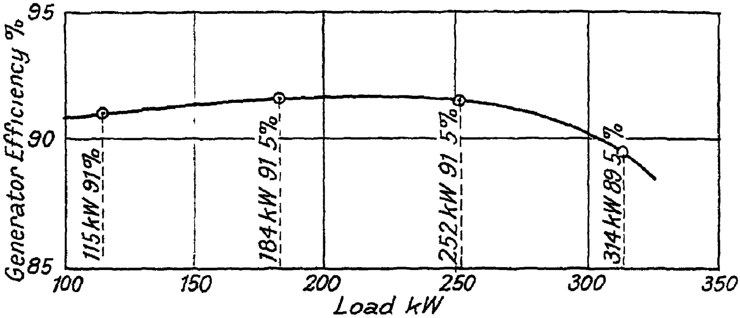


FIG 23 GENERATOR EFFICIENCY CURVE

Trials Report presented in 1927 to the Institution of Civil Engineers *

(*c*) **By Rope Brake or Hydraulic Dynamometer.** In the case of the rope brake the value of b h p may be calculated from

$$\text{b.h p} = \frac{(W - S)\ 2\pi RN}{33000}$$

Where W = Applied weight (lb)

S = Reading of spring balance (lb)

R = Radius from centre of crankshaft to centre of rope (ft)

N = Rev per min.

* Published by Wm Clowes & Sons, Ltd , 94 Jermyn Street, S W 1. 5s

In the case of the hydraulic dynamometer—

$$\text{b h p} = \frac{W \times 2\pi RN}{33000}$$

Where W = Net weight lifted or force exerted at end of arm (lb)

R = Effective radius of arm (ft)

N = Rev. per min

By making R of appropriate length the formula may be simplified to

$$\text{b h p} = \frac{WN}{K}$$

Thus, in the " Froude " dynamometer where R is made 5·2521 ft $K = 1000$, and b h p $= \dfrac{WN}{1000}$

By taking readings of W, S and N at regular intervals during the test runs, values of b h p may be calculated and the mean of these taken as the average b h p during the tests.

THERMAL EFFICIENCY AND EFFICIENCY RATIO

Heat Content per lb. of Initial Steam. The mean pressure and temperature of the steam at the stop valve may be derived from the log sheets, and the corresponding heat content from steam tables or diagrams This heat content should be diminished by the heat of water at a temperature corresponding to the steam pressure at the exhaust flange of the engine. In the example, the mean vàlues from the log sheet and steam tables are—

Pressure and temperature at stop valve—

173·7 lb. per sq in abs and 389° F.

Heat content = 1208 B Th U per lb

Pressure and corresponding temperature at exhaust flange—

1·64 lb. per sq. in abs and 119° F.

Heat content of water = 87 B.Th.U. per lb

Net heat content = 1208 − 87

= 1121 B Th U. per lb.

Heat Consumption of Engine. The steam consumptions of the engine in lb. per i.h p per hr, lb per b.h.p. per hr, and lb per kw. per hr. have already been calculated and the corresponding heat consumptions are obtained by multiplying these quantities by the heat content per lb. of initial steam thus—

At load	½	¾	4/4	5/4	
Steam Consumption	11 5	11 2	11 0	11 3	lb per i.h p per hr.
	13 5	12 45	11 9	12 05	lb per b.h p per hr.
	20	18 3	17 5	18 0	lb per kw per hr.

Heat consumption with an initial heat content of 1121 B Th U. per lb

12,900	12,550	12,350	12,700	B Th U. per i h p per hr.
15,150	14,000	13,350	13,500	B Th.U. per b h p per hr
22,400	20,500	19,600	20,200	B Th U per kw per hr

Thermal Efficiency η_{th}. The heat equivalent of work performed

$$= \frac{33000 \times 60}{778} = 2546 \text{ B.Th.U per h.p. per hr}$$

where 33000 = work equivalent of 1 h.p (ft.-lb. per min.)

778 = mechanical equivalent of heat (ft.-lb. per B.Th.U)

If this value is divided by the heat consumption of the engine the result gives the thermal efficiency, i e.

the ratio between the heat equivalent of work performed and the heat supplied—

In the example, the thermal efficiencies are—

On i h p basis	19 7	20 3	20 6	20 0 per cent
On b h p basis	16 8	18 2	19 1	18 9 ,, ,,

The importance of stating the basis upon which thermal efficiencies are calculated is apparent from this table.

Efficiency Ratio η_R. This may be defined as the ratio between the thermal efficiency of the actual engine and that of an ideal engine working between the same limits of temperature For steam engines, the recent report of the Heat Engines Trials Committee defines the ideal engine as a "Rankine" engine converting the *whole* of the energy available from the temperature difference established by the boiler and condenser into mechanical work. The thermal efficiency of such an engine is given by—

$$\eta_r = \frac{\text{Available heat drop per lb}}{\text{Heat received}}$$

$$= \frac{Is - I_2}{Is - Iw_2} = \frac{U}{Is - Iw_2}$$

where $U = Is - I_2$

Is = Total energy per lb of initial steam

I_2 = Total energy per lb of exhaust steam

Iw_2 = Total energy of water in hotwell

The pressure and temperature of initial steam are as measured on the boiler side of the stop valve, and those of the exhausted steam as measured in the exhaust pipe close to the engine. The temperature of the water in the hotwell is that corresponding to the pressure of steam in the exhaust pipe The limits are, therefore, the same as those used in calculating the thermal

efficiency of the engine The value of U may be calculated, or taken from tables of adiabatic heat drop. Vertical lines plotted on the Mollier diagram between the given pressure and temperature limits also give this value to the scale of the diagram

In the example, the available heat drop (U), from the Mollier diagram (173·7 lb. per sq. in abs. and 389° F to 1 64 lb per sq in abs) is 305 B Th.U per lb

$$Is \text{ (from Mollier chart)} = 1207 \text{ B Th U. per lb}$$

$$Iw_2 \text{ (as for thermal effy)} = 87 \text{ B Th U per lb}$$

$$\therefore \text{ Rankine effy : } \eta_r = \frac{305}{1207 - 37} = 27{\cdot}2 \text{ per cent}$$

$$\text{Efficiency ratio } \eta_R = \frac{\eta_{th}}{\eta_r}$$

Load	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{4}{4}$	$\frac{5}{4}$
at	72 4	74 8	75 8	73 8

The thermal efficiencies taken in the calculation are, of course, those on the i.h.p. basis, as cylinder performance only is being compared The results give a measure of the performance of the engine as compared with that of the ideal standard.

The foregoing examples give, in brief outline, the principal calculations necessary in comprehensive tests of steam engines. A selection of the calculations may be made to suit the purposes of any particular test

The conduct of steam engine tests and the tabulation of results have been the subject of considerable attention on the part of committees representing the technical institutions and other scientific bodies in this country. Reports on this subject will be found in the *Minutes of Proceedings, Inst. C.E.* (Vol. 134, p. 287), and in the 1927 Report already referred to. This latter report contains detailed codes and notes regarding the tabulation of trials, and the Appendices include notes

on the measurement of pressure, temperature, flow, and power, together with definitions and a tabulation of fundamental units and constants. The report is, therefore, worthy of the closest attention of all interested in the subject, and test results should be tabulated in accordance with the recommendations made by the committee.

MISCELLANEOUS TESTS

Governing and Speed Regulation. Variations of the normal speed of reciprocating steam engines are experienced as follows—

(*a*) Cyclical variations due to the variable turning effort on the crank pin.

(*b*) Variation due to change of load—the specified speed being reached at a given load and a limited variation being permitted between no-load and maximum

(*c*) Variation due to change of initial or exhaust pressure and temperature.

The magnitude of (*a*) is governed by the inertia of the flywheel, which is designed to give any desired coefficient of cyclical regularity, in accordance with the type of machinery driven, e g. $\frac{1}{250} - \frac{1}{300}$ for direct-driven alternators The characteristics of standard flywheels are well understood by the makers, but occasionally tests to determine the cyclic variation are carried out One method, adopted by Messrs Davey Paxman & Co , is as follows—

A motor driven by independent steady current is moved across the face of the revolving flywheel by means of a slide rest. On the end of the spindle is a disc containing a flexibly-held hardened steel pointer At each revolution of the motor a dot is made on the chalked face of the flywheel The spaces between the dots are then accurately measured round the periphery

of the wheel by a steel tape. Calculations show the amount by which the flywheel has run in advance or retard of the uniform revolution at normal speed.

Speed variation due to causes (*b*) and (*c*) is controlled by means of a governor, which either "throttles" the initial steam or varies the "cut-off" Governor tests may be undertaken to test the degree to which the governor is capable of regulating the speed or to test its sensitiveness, stability, or power Tests for speed regulation may be made by varying the load with constant initial and exhaust steam conditions or by varying the steam conditions with constant load. In the first case, the load should be increased in steps from zero to maximum and vice versa—the speed being noted when steady conditions are reached after each load change. In the second case, the steam supply should be throttled by means of the stop valve and the speed and load noted at each change In both cases readings of steam pressure and initial temperature should be taken The readings obtained make it possible to calculate the "permanent" speed variation consequent upon the load changes. The instantaneous variations may also be noted so that the percentage maximum "momentary" variation may be calculated. The time taken for the engine to resume a steady speed after any load change may be noted

The speed variation per cent from normal is expressed by the formula

$$\frac{(N_1 - N_2)}{N} \times 100$$

where N_1 = max rev per min (at a lower load)

N_2 = min. rev per min (at a higher load)

$$N = \frac{N_1 + N_2}{2}$$

The sensitiveness of a governor may be tested by noting the change of speed required to set the governing mechanism in motion The initial and final speeds during each change should be noted, together with the corresponding loads—steam conditions being kept constant during the test

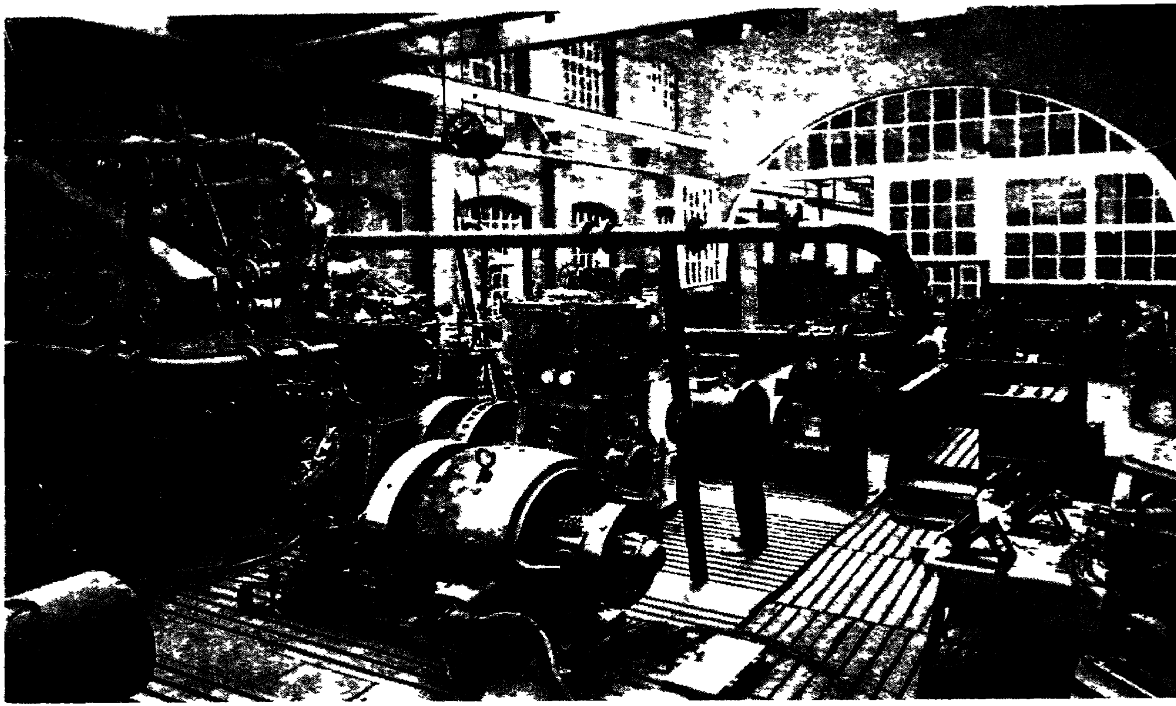
Records of stability may be made where governors are fitted with speed-adjusting devices by noting the maximum and minimum speeds at which the governor may be set at no-load and full-load The position of the adjusting device should be noted at the same time.

Governing power may be tested by noting the force required to hold the governor collar in its original position after a given change of speed, consequent upon an adjustment of the regulating device. The test should be carried out at full-load and no-load, and the mean of the forces multiplied by the travel gives a measure of the capacity of the governor

PART III

TEST BED EQUIPMENT AND COMMERCIAL TESTING OF HIGH-SPEED ENGINES

The notes which follow describe the equipment and methods used by Messrs Belliss & Morcom for the testing of their well-known high-speed engines. Fig 24 gives a view of a portion of their test beds, and Fig 25 shows the water-resistance tanks and choking coils (see page 2088). The latter are the square black tanks between the long earthenware tanks which provide for the non-inductive load. The Heenan & Froude dynamometers are visible in the background, coupled to engines under test The writer is indebted to Messrs Belliss & Morcom for the use of the illustrations and



(Belliss & Morcom, Ltd)

FIG 24. PORTION OF TEST BEDS

for details of their practice which they have kindly furnished—

Test Equipment. One of the chief necessities during a test is to provide steady conditions of steam supply and load. In view of modern practice, and the tendency towards higher steam pressures and temperatures, water-tube boilers are essential. The whole of the steam-raising plant, boilers, superheaters, pipes, must be good for the highest pressure decided upon, and seeing that the cost of water-tube boilers and pipe-work for pressures above about 200 lb. per sq in. commences to rise rapidly, it will need careful consideration to determine whether the amount of testing likely to need high pressure is sufficient to warrant the extra cost, or whether it would meet the case to test up to, say, 200 lb. per sq. in. only. If the future is taken into consideration it will probably be decided to install boilers for at least 350 lb per sq. in. working pressure, and 700° F. total temperature Any manufacturer who aims at being really progressive will seriously consider the installation of an alternative boiler and pipe-work to test up to 1000 lb. per sq in, for experimental work.

A wide range of conditions has to be met, probably from 65 to 70 lb per sq in, from old colliery boilers upwards, and from dry saturated steam up to 650° F to 700° F. temperature. It will be necessary to install a separately fired superheater, or to have superheaters of the ordinary type, but capable of being put out of action without risk of burnt tubes

Exhaust conditions will be similarly variable If reciprocating engines only are to be considered, a vacuum of 26 in (bar 30 in.) in the engine cylinder is about all that can be utilized. For this, a surface condenser with motor-driven Edwards type air pumps is most convenient Depending on the number of engines

(*Belliss & Morcom, Ltd*)

FIG. 25. LOAD RESISTANCE TANKS IN TEST HOUSE

likely to be tested together, it will be useful to install two or more condensers, of different sizes. The air pumps of each condenser will discharge to a separate tank mounted on a weighing machine. The tank will be fitted with a large pipe with visible outlet, which can be quickly opened or closed by a stop cock. If desired, the arm of the weighing machine can be arranged with an electrical contact to ring a bell when the arm lifts, though this is not always satisfactory, as the condenser discharge on light loads is often erratic, and may make the arm jump before the tank is full The capacity of the tank will be proportioned to the size of engine it is proposed to test.

A test of an engine exhausting against a back pressure is carried out by throttling the exhaust by means of a stop valve close to the cylinder, the steam going to the condenser as usual. Extraction engine tests are arranged so that the exhaust from the L.P. cylinder goes to one condenser and the steam from the pass-out main to another The piping will also have to be arranged for exhausting to the atmosphere. If in a residential neighbourhood it may be necessary to fit the atmospheric pipe with an exhaust head to deaden the noise and to obviate trouble with moisture

All pipework will be arranged so that it is as far as possible self-draining, with a gradual fall from boilers to engines and from engines to condensers. It will be carried along the length of the test house with branch pipes at suitable intervals to serve individual berths. As the stop valves of different size engines will come in different positions, the steam pipe to the engine will have to be rigged before each test. A selection of short straights and bends should be kept for this purpose. Bends with loose split flanges are useful, as they can be turned to any angle. Flexible metallic piping is sometimes useful to couple up to the exhaust ranges

The load will be applied either by means of a direct-coupled water brake or by water resistance. In the former case the brake has to be accurately set up and lined out. Matching couplings will be necessary to cover a range of standard engine sizes.

Where an engine is to be tested coupled to its own generator more elaborate arrangements are required The electrical load can be provided by C.I plates immersed in a tank arranged as a water resistance with the water flowing through it to keep it cool. The plates should be arranged with insulated handles and rollers, so that the distance between them can be regulated to vary the load.

For alternating current, inductive load will be required to give a variable power factor This is best provided by choking coils These will also be immersed in tanks and provided with tappings, so that a portion of each coil may be cut out if not wanted

The switchgear required may be mounted on a permanent board or on a portable board, which can be moved near the test berth which is in use

It is convenient to have the artificial load divided into sections, each governed by a switch, so that the load can be arranged to suit each job and can be increased gradually, apart from adjustment of the individual plates A main switch is necessary which can be of an ordinary quick-acting open type for d c work of small capacity For a c an oil-immersed triple pole switch will be used

It is usual to test the field resistance belonging to the job with its own machine, so as to ensure that it is of the correct range and graduation.

Ordinary commercial ammeters and voltmeters can be mounted on the switchboard, but it is convenient to have specially accurate meters in a glass-sided office, where they are not exposed to dirt and rough handling.

The office enables readings to be taken and figures worked out in cleanliness and comfort.

Concrete foundations must be provided sufficiently heavy to carry the largest plant likely to be tested. On the top of this should be strongly bolted and carefully levelled "T" slot castings to take the heads of holding-down bolts. For ease in erection it is not necessary that these bolts should be threaded through the holding-down bolt holes in the bed plate, as it is quite satisfactory if the engine is fastened down by means of straps. The surface of the concrete under the "T" slots should have a slope so that water drains away.

Preliminary Runs. Before the actual test is carried out, the engine should do as much preliminary running as possible If possible, a complete run of the same duration as the test should be made The longer the run the more chance there is of defects showing up before the official test, and there is also an opportunity for piston rings, metallic packings, and bearings to bed themselves in

At the first start, oil is put into the engine bed plate to the proper level, and the sight feed lubricator filled with the proper quality of cylinder oil Cylinder oil is also introduced through the cylinder vase lubricators, and the indicators and indicator gear are fitted

All cylinder drains are opened, and the stop valve is opened slightly so as to warm the cylinders After a quarter of an hour or so the stop valve is opened further, and the engine started slowly under steam, and exhausting to atmosphere. All inspection doors are off, and a careful watch is kept to see that a correct supply of oil reaches every bearing, the main guides, eccentrics, etc When it is certain that this is the case, and that there is no unusual noise through moving parts fouling or other causes, and that a good oil-pressure is obtained, the doors are fastened, and the engine gradually

brought up to speed, with no-load on the generator or the water brake. Points to watch are that the steam temperature is kept down, the pressure in the steam chest, as shown by the guage, is normally low, the speed of the engine does not exceed the designed running speed as the stop valve is opened, and that the governor takes charge satisfactorily, as this speed is reached. The no-load speed with speed-adjusting gear slacked off, is known as the "ball speed," and should be about 5 rev. per min, below the running speed.

If everything is satisfactory, a light load may be applied after a short period of running. In the case of a generator drive, this is the time to check the excitation of the machine, and that the meters are reading the right way round.

The load may now be brought up gradually, as time permits. When full load is reached, the steam temperature can be gradually raised to the specified figure, an ample supply of oil being worked into the cylinders. A thermometer pocket should be placed as close to the governor valve as possible, and it should be long enough to project well into the path of the steam.

As soon as full load is obtained, indicator diagrams may be taken to see that the shape of the diagram is approximately correct, and that the valve setting is as it should be. The governor valve opening and the chest pressure compared with the boiler pressure, are also useful indications as to the manner in which the engine is carrying its load and with what sort of a margin.

When load, steam-pressure, and temperature are steady, a consumption test may be taken. The arm of the weighing machine is nearly balanced, and the outlet cock closed. As soon as the arm rises, the stop-watch is started. The movable weight is moved along a hundredweight or so, and the time noted when the arm rises

again. This process is repeated until the tank is full, or until a reasonable time (say, $\frac{1}{4}$ hr.) has elapsed. The tank is then allowed to empty. During the time the consumption is taken a watch must be kept to ensure that steam and load conditions remain steady.

The consumption is then worked out from—

$$\text{lb per b.h.p. per hr.} = \frac{\text{cwt} \times 112 \times 60}{\text{b h.p.} \times \text{time in minutes}}$$

After running for a sufficient time to determine that all is in order, the governor trials are made. With steady full load and without touching the governor adjustment in any way, the main switch is opened. The maximum momentary speed is noted, also the steady no-load speed. The latter is usually specified to be not more than 3 to 5 per cent above the normal running speed.

The engine speed is then adjusted to normal again, and the main switch closed The momentary drop and the steady running speed are noted.

When the engine is direct-coupled to a water-brake, load can be thrown off suddenly by a special unloading gear, fitted to the newer pattern brakes

The overload and light load tests can now be taken. Indicator diagrams and steam consumptions at several loads are not always required by purchasers, although, if time permits, they may be taken as a matter of interest

All small oil and steam leaks and other imperfections are carefully noted, and remedied by the fitters when the engine is shut down Provided that everything is so far deemed satisfactory, the engine may be shut down and is ready for the official test in the presence of the purchaser, or consulting engineer

Official Trials. The engine is started early in the morning, and as soon as possible load and steam conditions are made steady. A careful log is kept, with

readings every quarter of an hour. Specimens of log sheets are given in Figs. 26 and 27. The generator temperatures are taken by thermometers wedged against the outsides of the field windings

ENGINE N°

ENGINE LOG.

TIME.	STEAM					VACUUM AT		REVOLUTIONS BY TACHOMETER	
	BOILER PRESSURE	STEAM CHEST PRESSURES			TEMP	COND	ENGINE		
		H.P	I.P.	L.P					

FIG 26

GENERATOR N°

GENERATOR LOG.

AMPERES.				VOLTS.	kVA	WATTMETER READINGS		TOTAL kW	EXCITATION		POWER FACTOR
A	B	C	MEAN.			1	2		AMPS	VOLTS.	

FIG. 27

ENGINE N°

WATER CONSUMPTION LOG.

TIME.		WATER INTO TANK.	LOAD.				STEAM.		VACUUM AT ENG
CLOCK.	INTERVAL		AMPS.	VOLTS.	kW	B H P	PRESSURE	TEMP	

FIG 28

Normally, the test follows the practice outlined for the preliminary trial After about two hours' running consumption tests are taken, the figures being entered on a log sheet similar to the specimen shown in Fig 28. Indicator diagrams are also taken. Each card may have particulars noted on it as to engine number, end of cylinder, steam pressure and temperature, load, speed and spring strength. Diagrams must be taken from each position in quick succession, and the load must be kept steady. From the indicator cards the mechanical efficiency is calculated.

$$\text{Thus: Mech effy} = \frac{\text{b h p.}}{\text{i h p.}}$$

where b h p $= 2\pi R \times W \times$ rev. per min

R = Length of the brake arm, feet.

W = Applied weight, lb

The setting of the brake for any particular load is obtained from the formula

$$W \text{ lb} = \frac{\text{h p} \times \text{constant of the brake}}{\text{rev per min}}$$

The indicator cards are worked out by means of a planimeter in the usual way Where a range of standard engines has to be tested, it is useful to calculate and tabulate the constants $C_2 = \frac{L_1 A_1}{33000}$ for each standard. This procedure saves a large amount of time and trouble, during individual tests.

Thus Constant C_2

$$= \frac{\text{Mean area of piston (sq in)} \times \text{stroke (in)}}{6 \times 33000}$$

For double-acting engines.

$$\text{m e p} = \text{Pm}_1$$

$$= \frac{\text{Mean area of top and bottom cards} \times \text{spring strength}}{\text{Mean length of diagram}}$$

$$\text{i.h p} = \text{pm}_1 \times \text{rev. per min} \times C_2$$

Where a generator is direct coupled,

$$\text{b.h.p} = \frac{\text{kW}}{\cdot 746 \times \text{generator effcy.}}$$

On completion of the full load run—which should last at least long enough to show steady temperatures on the generator (i e four to six hours)—the governor trials are taken. The set is then shut down to check generator temperatures—particularly those of such parts as the commutator and armature windings, or, in the case of an alternator, the revolving field magnets.

It is also desirable to take the temperature of the oil in the engine bedplate. As soon as temperatures have been noted, the set is started up again, and run on overload, and then, if time permits, on light loads.

It is not usual to take lubricating oil consumptions as, with totally enclosed forced lubricated engines, the crankchamber consumption is very small and difficult to measure with accuracy, except over long periods

The information obtained during the tests is carefully compared and graphs drawn to show the effect of varying pressure, temperature, and vacuum. These are of great assistance to the drawing office and estimating departments in quoting for engines where steam consumption guarantees, under penalty, are required.

SECTION XXXVII

TURBINE FITTING AND ERECTING

BY

J J STOKES

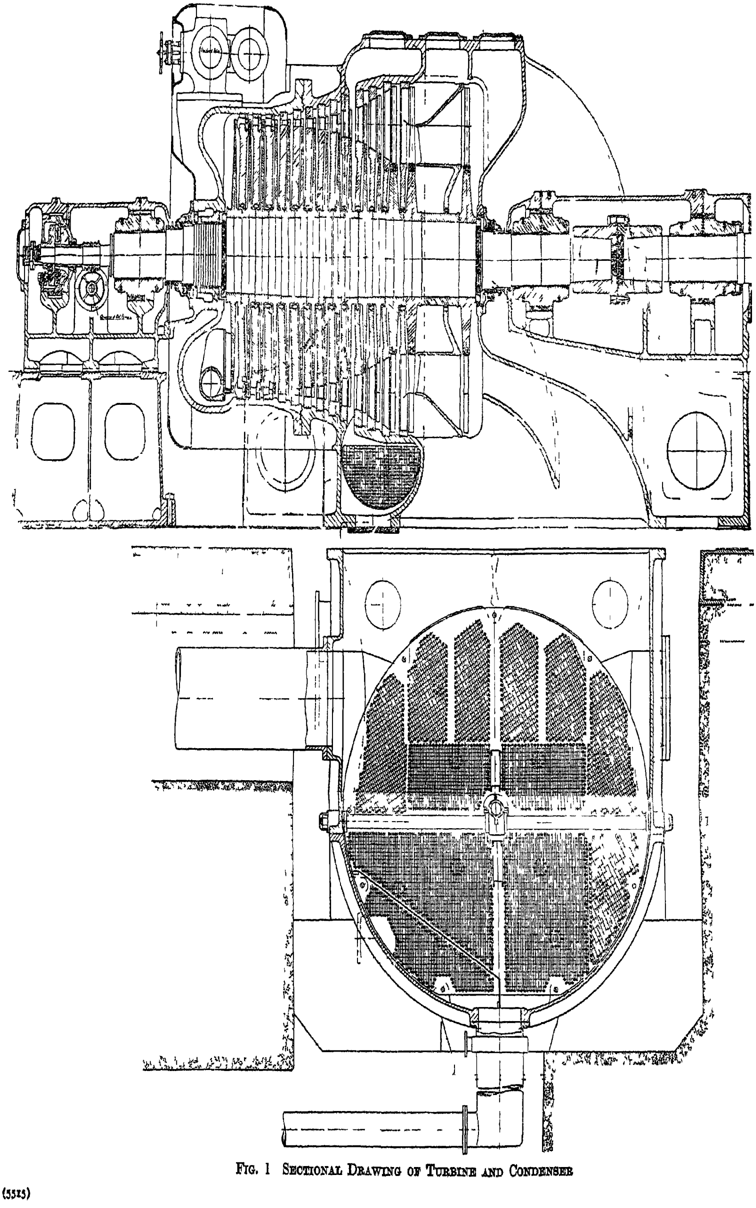


FIG. 1 SECTIONAL DRAWING OF TURBINE AND CONDENSER

SECTION XXXVI

TURBINE FITTING AND ERECTING

THE modern steam turbine is rapidly superseding the reciprocating engine, and few erectors of the latter find themselves at home when called upon to carry out the erection of the former type of prime mover. The turbine being a high-speed machine, and subjected to high pressures and temperatures, critical speeds, stresses due to expansion, and other characteristics, calls for carefully-constructed foundations and special attention to certain parts of the erection.

It is not intended to go into details of fitting or the use of various engineers' tools, but to assist the young engineer who is given charge of the erection of a steam turbine generating plant to go about it in a workmanlike and methodical manner, and to acquaint him with the peculiarities of this type of machine We will therefore assume, then, that the reader has been given charge of the erection of a steam turbine exhausting into a surface condenser with suitable auxiliary plant, and driving an alternator with a normal rating of 10,000 kW output, similar to that shown in Fig. 2 Fig 1 shows a sectional arrangement of a plant of this type, and is useful for further reference

PREPARATORY WORK

Before commencing any erection at all, it is most essential that the use of a small office or shed be obtained as near to the site as possible, where drawings, information, and records can be kept clean and easily accessible. Drawings left lying about the job are liable to get lost

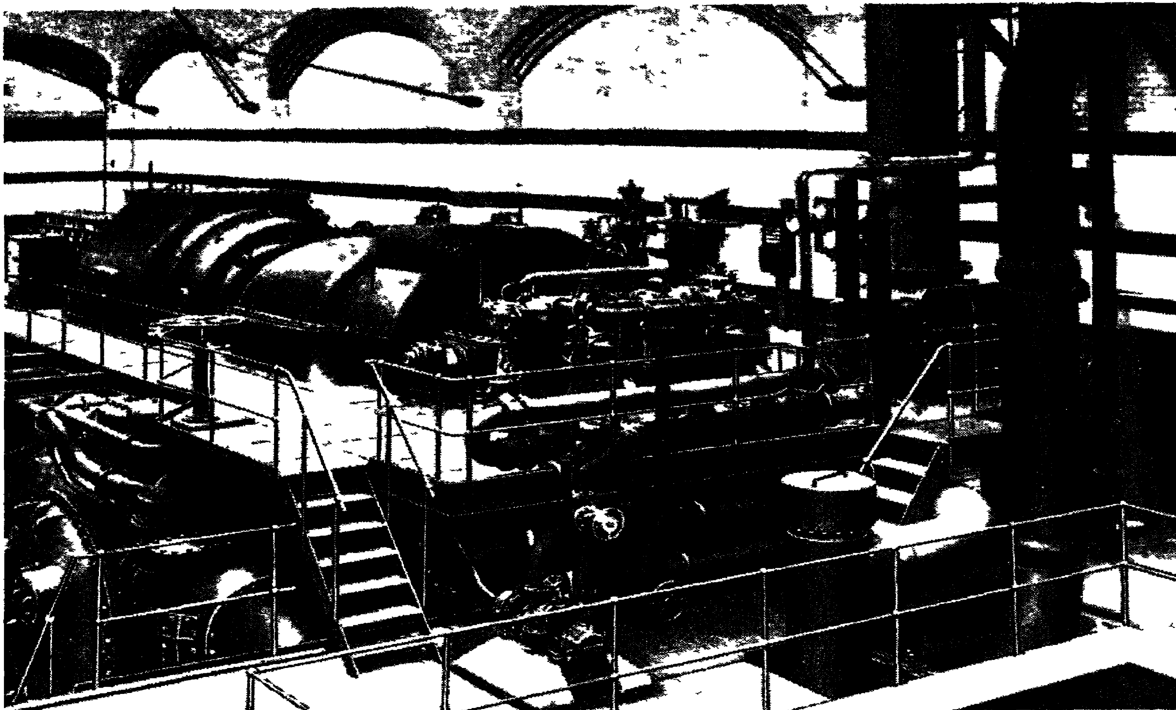


Fig 2. 10,000 kW Turbo-generating Plant

or the dimensions obliterated, and serious delays and mistakes may follow.

In addition to the office, obtain or construct another shed or locker, where tools, slings, and details can be stored methodically. Arrange the various tools so that you can see at a glance the one required for a particular job without wasting perhaps half an hour looking for it. Arrange this latter shed as near to the job as possible and on the same level as the turbine, where the major part of the work is to be carried out, in order to eliminate as far as possible walking about and climbing up and down ladders.

It will therefore be seen from the above that it is well worth while giving these few preparatory points serious consideration

FOUNDATIONS

The construction of the foundations is a most important factor, and it is the erecting engineer's duty to his company to see that they are carried out in a satisfactory manner. Before commencing any foundation work at all the subsoil's nature should be first ascertained and, if this be marshland or some other sort of soft ground, the site will have to be suitably pile-driven to carry the raft which supports the main structure (see Fig. 3), otherwise sinking may take place, causing vibration troubles, etc., due to misalignment The most suitable type of foundation block for carrying this class of machinery is made of concrete with an internal steelwork system supporting the main joists, carrying the sole plates, this internal steelwork being buried in the concrete (see also Fig. 3).

Having said a few words about the general construction of the foundations, we will assume that a suitable raft has been supplied by customers, and that the erection of the internal steelwork is about to commence,

but before this can be done the datum points which are to be worked to must be fixed

DATUM POINTS

Take all dimensions from three distinct datum lines. The finished turbine room floor level for all vertical dimensions, and the building walls or centre lines of any adjacent sets for all horizontal ones. Take as many dimensions as possible from these points and dispense with small progressive errors of measurement.

ERECTING THE INTERNAL STEELWORK

Having fixed the datum points, the erection of the internal steelwork can begin. The whole of this has to be erected before any concreting is carried out to form a complete steel structure independent of concrete. The top grillage or soleplate joists are mounted on stanchions. The necessity of carefully bedding these to ensure them not sinking is most important, thus making the load on the joists largely independent of the concrete for support.

The top surface of the soleplate joists should be rough machined before erecting, thus enabling them to be set level and to allow the machined packers to obtain a good seating. All steelwork should be drilled at the makers' works, and should be marked by them in two places to facilitate erection, otherwise much time may be lost in hand drilling on site and locating the various pieces to drawing.

It is advisable to grout-in the feet of the stanchions before pouring the main concrete to ensure that they are solid.

CONCRETE WORK IN FOUNDATION BLOCK

The following are points which should be very closely watched—

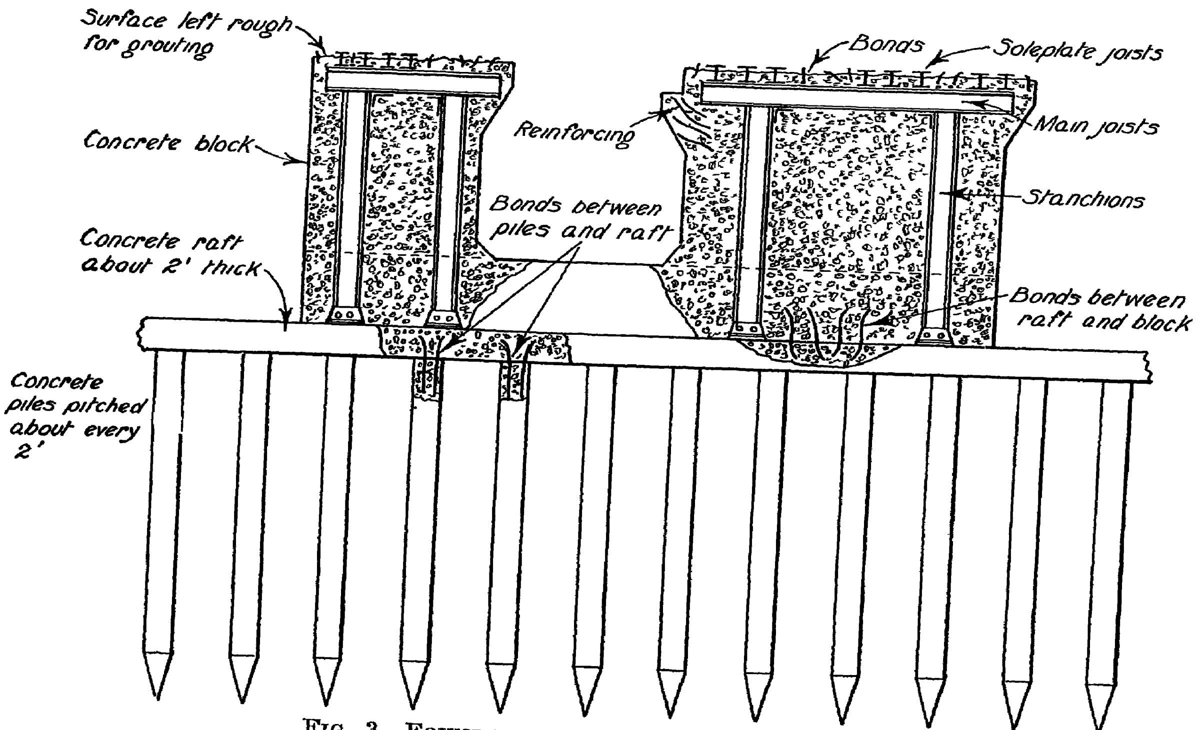


FIG. 3. FOUNDATION FOR TURBO-GENERATOR

(*a*) **Materials.** Concrete for this class of work is made from stone, sand, and cement. The stone should be of a good, clean, hard nature, such as granite or limestone chippings, free from dust, and should be of a size that will pass through a 1 in. diameter ring and not through a $\frac{1}{2}$ in. one.

The sand should be coarse and well washed, such as river bed or shore sand Should the sand contain more than 5 per cent of marl or other foreign matter, it should be washed before use. Quarry sand usually contains marl, and washing being an expensive item, preference should be given to the shore or river bed sand where this is available, avoiding that which contains coal. The cement should be the best quality obtainable, and of a slow setting nature. This should be carefully stored in a dry shed until it is required for use.

It is most important that all materials used in the mixing of concrete are free from oil

(*b*) **Proportions of Materials.** Having decided on what proportions of the materials to use, it is most important to see that these are adhered to In mixing concrete the proportions are made by volume, and not by weight. Assuming that the mixture is to be a one, two, four. Then to 1 cub. ft. of cement 2 cub. ft of sand are added and 4 cub. ft. of stone. The quantities must be accurately proportioned in special measures made for the job, and not by wheelbarrows or shovelfuls.

(*c*) **Mixing.** The best method for mixing large quantities of concrete is undoubtedly by means of a mechanical mixer, and one of about 8 cub. ft. capacity, driven by a small petrol engine, is suitable for a foundation of the size in question. The materials are first put into the hopper, which transfers them to the mixer, where they are thoroughly mixed, water being added. The actual time taken to mix a batch of concrete of this

quantity should be about 2 min, but the time will vary according to the type of machine and the materials used.

(*d*) **Pouring.** Having previously made the surface of the raft as rough as possible by chipping, should it be necessary, this should be washed with a hose to remove the dust and to make it damp in order to obtain a good bond between the raft and block, care being taken not to leave any pools of water. As soon as a batch of concrete is mixed it should be poured into place without delay, and once the pouring is commenced it should be made continuous until within about 2 in. of the top of the girders carrying the soleplates, this remaining few inches being left for grouting-in purposes. The mixture should be thoroughly tamped throughout the entire pouring process to expel all air and thoroughly worked under all steelwork, leaving the top surface as rough as possible, and sinking in a quantity of $\frac{3}{8}$ in. diameter iron rods about 18 in long, leaving them standing proud of the concrete about 6 in. These are afterwards bent over to form a bond between the grouting and the main block It is of vital importance to see that the concrete is not dropped into place, but that it is passed down chutes at an angle not more than 45 degrees with the horizontal plane. If the concrete is dropped into place the stone chippings become separated from the sand and cement, resulting in the mass not being homogeneous

It is important to keep all concrete work free from oil, and when making a bond between two layers, such as between the raft and block or between the block and the grouting, to chip away any greasy surface. During the setting period the mass should not be exposed to frost, direct rays of the sun, or winds.

(*e*) **Grouting.** The grouting-in of the soleplates is carried out at a later stage of the erection, the grout

usually consisting of one part of cement to two parts of the sand previously mentioned; these are thoroughly mixed until liquid enough to flow under the soleplates. The surface of the block is first washed with a hose pipe, and while it is still damp the grouting is run in and thoroughly worked under each soleplate by means of a thin wooden lath. The grouting is carried up to a level indicated on the drawing but will contract during the setting, this amount being made up afterwards when setting the tiles of the flooring.

For lining-out purposes it is advisable to secure by rag bolts to each end of the block a piece of 3 in. channel iron, to which is fixed the fine wire line representing the centre line of the set (see Fig. 4) These channel irons are afterwards taken down and the rag bolts cut off. Before taking any of the shuttering down or lifting any castings into position, ascertain whether the concrete has properly set. This will probably take about two weeks after the final pour, but the time will vary according to the atmospheric conditions.

DISTRIBUTION OF MATERIAL

During the construction of the foundations the material to be erected will begin to arrive. The distribution of this in the available space should be given careful consideration, in order to minimize crane lifts and to leave plenty of space for working.

Large pieces first wanted, such as condenser, bottom half of cylinder, soleplates, and pedestals, should be placed near at hand Pumps and parts of the turbine, such as the spindle, should be placed where they will not be damaged and should be covered up with sheets Pipes may be stored outside if the room in the station is restricted, these can be easily rolled inside as required. All electrical apparatus must be stored in a dry place.

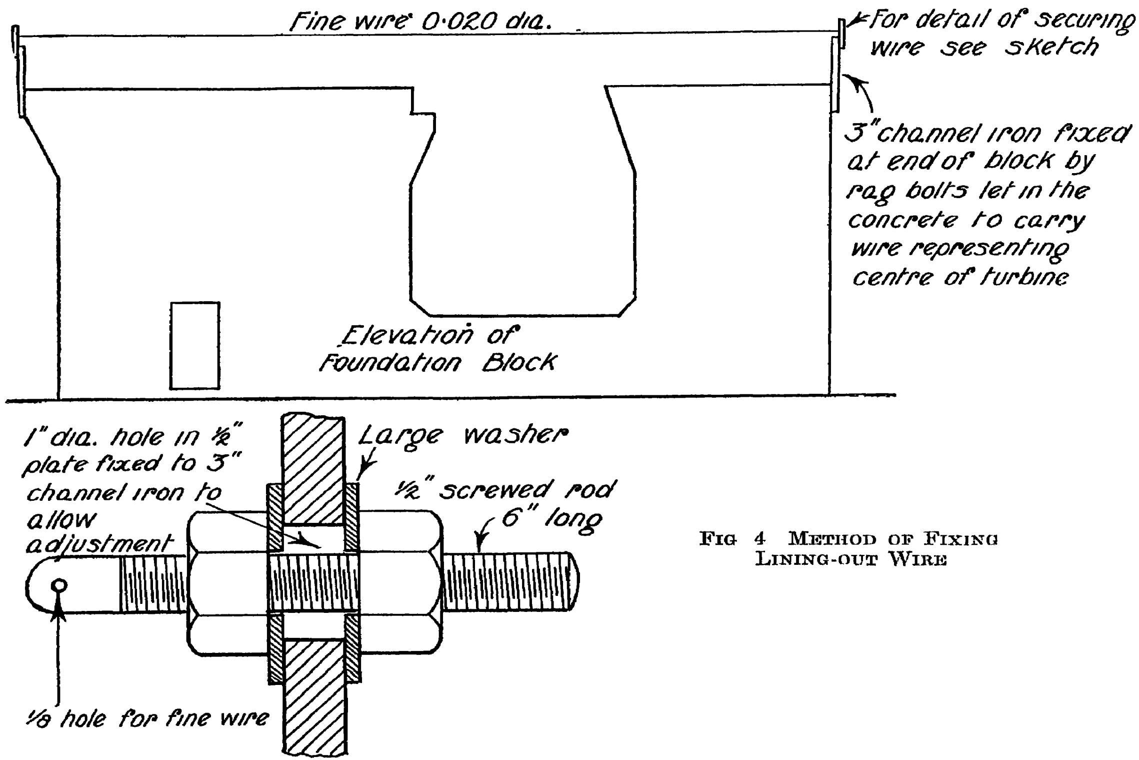


Fig 4 Method of Fixing Lining-out Wire

Having given the foundations sufficient time to set, the erection of the plant may proceed.

BEDDING THE BEARINGS

Bed each bearing to its respective journal by smearing the journal with a mixture of raddle or red-lead powder and oil Apply the marking to the journal as thinly as possible, distributing it first with a small piece of rag and afterwards rubbing it with the palm of the hand until it is practically all removed again. Thick marking only gives false readings The bearing bottom half is thoroughly cleaned and placed in position on its journal; it is then given a semi-rotary motion which marks the high places, these being afterwards removed with a half-round scraper and the operation repeated until it is uniformly marked. The sides are afterwards scraped away about 0·002 in. deep, leaving the journal bearing on an arc of only 60° at the bottom of the bearing. The top halves require very little bedding at all, and only the very high places should be removed. This work can be carried out while waiting for the foundations to set.

CHECKING THE STEELWORK

Check the top grillage carrying the sole plates for being level, and should these have moved slightly due to the concrete, mark the places where the packers are to be inserted and adjust these by filing to a level and straight-edge, so that a good seating for the packer will be obtained. Fix the fine lining-out wire representing the centre line of the set in position (see Fig 4), and by means of an engineer's plumb bob suspended from the wire, mark the centre line on the steelwork with a fine flat chisel.

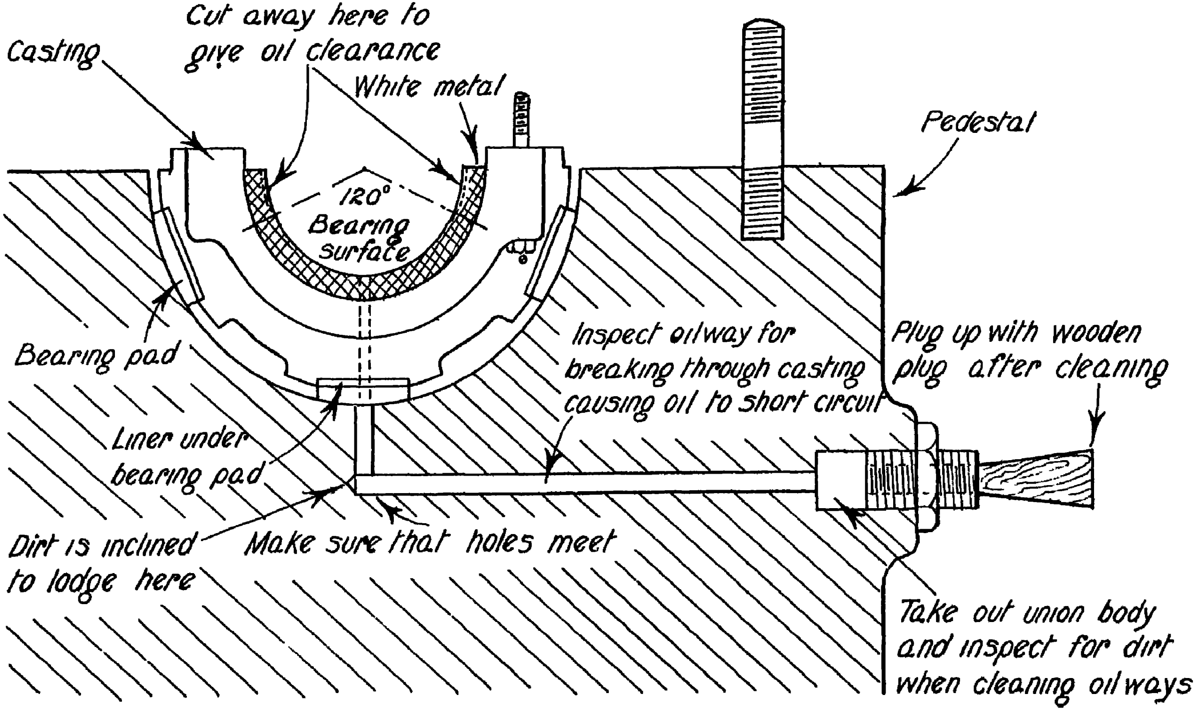


FIG 5. BEARING AND OIL SUPPLY HOLE IN PEDESTAL

ERECTING CONDENSER

Mark both centre lines on the exhaust flange of the condenser for setting purposes by means of a scriber. Set all stools carrying the spring supports for condenser feet on temporary packing, as near to drawing as

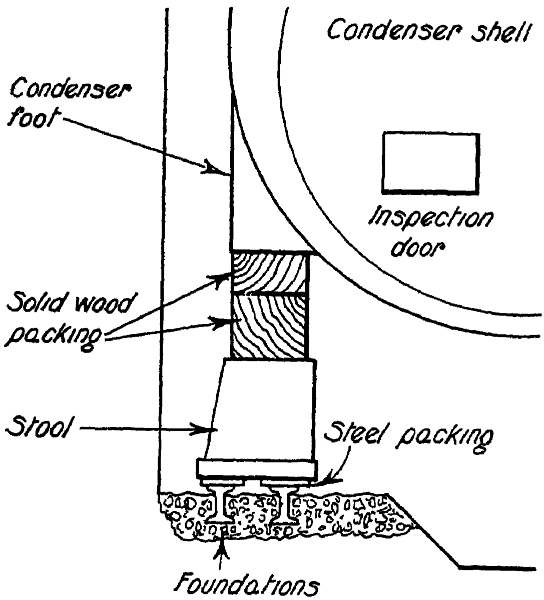


FIG 6 CONDENSER ON BLOCKS OF TIMBER

possible, and lift the condenser shell into place on solid blocks of timber resting on the stools (see Fig 6), so that the face of the exhaust flange is approximately 1 in below its final setting. If possible, arrange the timber so that a jack can be afterwards inserted between the stool and the condenser foot for lifting purposes without disturbing it. Clean the exhaust flange face by rubbing a smooth flat file over it, and level up the condenser, using a high-class level and a

parallel straight-edge placed across this face to obtain average levels and not local ones It is most essential, before any levelling up is commenced, that you satisfy yourself that the straight-edge is true and parallel, and that the level is reading correctly. By

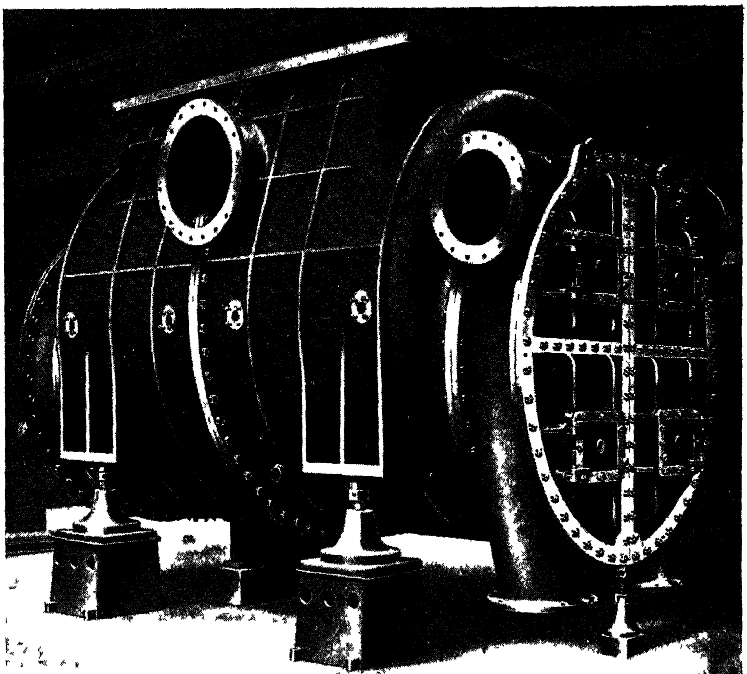


FIG 7. SHELL OF SURFACE CONDENSER

means of the centre lines marked on the exhaust flange face set the condenser in position relative to the horizontal datum points, making sure that the level is not disturbed. The fitting of the spring supports under the condenser feet is carried out at a later stage of the erection. Having fixed the condenser in its temporary position the tubing can now proceed, afterwards making

the water-box joints with a mixture of red and white lead.

It is advisable at this stage to lift into position the atmospheric exhaust valve and the pipe connecting it to the condenser, making sure that it is properly supported, allowing for the condenser being set about 1 in. low. Do not attempt to make this joint until after the main exhaust joint is made.

SOLEPLATES

It is most important that all soleplate faces and the bases of pedestals, etc., coming in contact with them should be thoroughly cleaned before assembling.

Bolt the exhaust end soleplate in position to the cylinder, fitting the dowels in place Rub with dry graphite the under side of the thrust pedestal and the face of the soleplate, in order to reduce the force necessary to move the pedestal when the cylinder expands Bolt the soleplate to the pedestal, replacing the expansion washers by temporary clearance ones to hold the faces tightly together, leaving the major clearance in the holes at the front of the stud to allow the cylinder to expand freely (see Fig. 8).

Assemble the outboard pedestal on its soleplate. A sheet of insulating material about $\frac{1}{16}$ in. thick is usually placed under the pedestal, also holding-down bolts and dowels are properly insulated to prevent the circulation of currents through the shaft and steelwork by way of the pedestals, which causes the journals to pit. It is not necessary to fit this insulating material until after the rotor has been threaded, as it may become damaged and cause the insulation not to be satisfactory; therefore the pedestal can be assembled directly to the soleplate for preliminary setting purposes, care being taken to insert it before finally lining out the rotors.

When assembling this pedestal to its soleplate it is important that the clearances between the bolts and the holes in the pedestal feet are as uniform as possible, in order to allow final adjustments, if necessary, after the soleplate is grouted in.

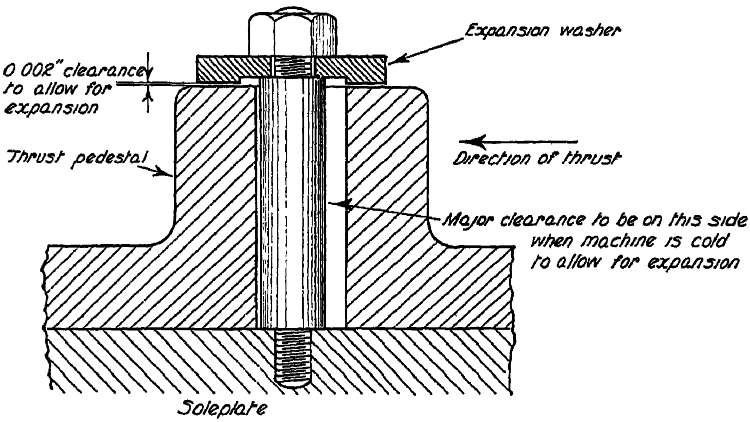


FIG. 8. THRUST PEDESTAL EXPANSION STUD AND WASHER

SETTING THE BOTTOM-HALF CYLINDER

Having bolted the soleplates to the cylinder and thrust pedestal, the thrust pedestal already being assembled to the cylinder bottom half, this can now be lifted into place in one piece, having first cleaned the exhaust flange face, placing under the soleplates temporary packing pieces approximately the size called for on the drawing, the packing being made up of several thicknesses to allow for adjusting.

Check each half of the cylinder gland bores for being symmetrical about the horizontal joint of the cylinder, using a straight-edge and micrometer to obtain this measurement, making a record of same, as any discrepancy has to be allowed for when levelling up the cylinder

Level up the cylinder both axially and transversely, using the parallel straight-edge and high-class level to obtain general readings and not local ones

In levelling up axially, allow for any machining error that would throw the gland bores unequal about the horizontal joint of the cylinder.

For example, suppose the gland bore readings taken as previously explained are as follows—

High pressure end bottom segment, 6·012 in.

High pressure end top segment, 5·988 in.

Exhaust end bottom segment, 6·003 in.

Exhaust end top segment, 5·997 in

Then the straight-edge placed on the cylinder joint axially from high pressure to exhaust gland bore must be made horizontal with a 0·009 in. packer placed underneath it at the exhaust end. Align the gland bores coaxially with the fine wire datum, making sure that the cylinder level is not disturbed during the operation. Set the outboard pedestal bore also coaxially with the wire, having previously levelled up the pedestal, and set the centre line of the housing the correct distance from No. 1 alternator bearing, as shown on the drawing.

CLEANING AND TESTING PEDESTAL OIL-WAYS

At this stage it is advisable to clean and test the oil-ways in the pedestals, also any sealing supply holes for the cylinder glands in the casting, for once the alternator rotor is in position it is not removed again

Thoroughly clean each passage by applying the compressed air pipe to one end, and working a piece of wire up and down the hole to dislodge any borings which may adhere to the casting by means of rust. If the pedestal is fitted with a union body it is advisable to remove this, as small particles of dirt are liable to lodge behind it (see Fig. 5). This figure also shows another place where

dirt is liable to lodge, namely, at the junction of the two holes

Make sure that the two holes meet properly, allowing the full supply of oil. This is done by shining a small torch up one hole and looking down the other.

Having thoroughly cleaned the holes, plug up the lower end and fill up with paraffin to test the oil-way for not having broken through the casting at any point or come in contact with some porous metal, thus causing the oil supply to become partly short-circuited. As soon as you are satisfied, take out the wooden plug and allow the paraffin to run out. This will help to give the oilway a final clean

Having satisfied yourself that these passages are thoroughly clean and tested, plug up each end with a properly formed large-headed wooden plug Do not use plugs made of cotton waste or rag, as these are liable to get left in, causing serious trouble, also cotton waste contains grit which may get deposited in the oil-way

From now onwards during the erection these plugs must be kept in place, except when taken out to lift a rotor into position or to couple-up a pipe Lift the bearings into position and ascertain that the hole in the bottom pad of each bearing coincides with the oil supply hole in the pedestal, when the stop pegs in each bearing for locating it laterally and to prevent it rotating either way are fitted. Another important point to watch closely is that any liners used under the bottom pads have oil holes in them

CENTRALIZING TURBINE SPINDLE IN THE GLAND BORES

With the glands removed, lift the spindle into position and centralize in the gland bores by means of the bearings, using the liners under the pads for this

purpose. If necessary, to obtain the vertical measurements, lift the cylinder cover into place, making sure that the faces are together. Always use an inside micrometer where possible to obtain these readings, keeping records of the sizes of liners under all bearing

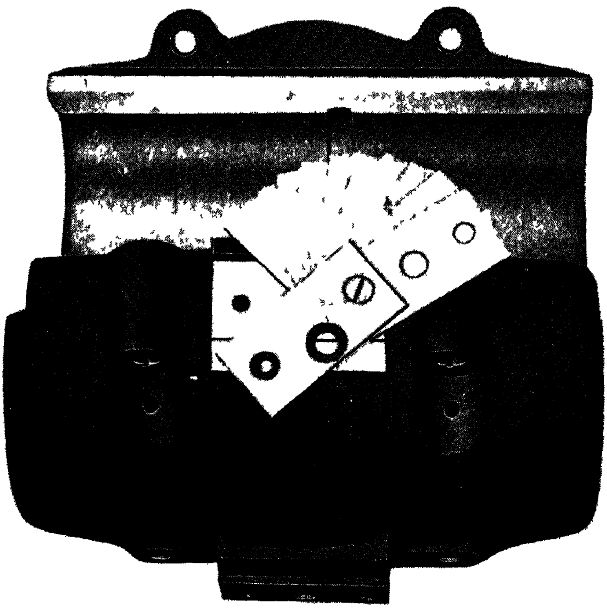


FIG 9 SHOWING BEARING ADJUSTING LINERS

pads, so that solid ones can be fitted after the first run on the machine. Fig. 9 shows a bearing of this type with adjusting liners removed from underneath one of the pads. It is advisable to mention here that whenever the spindle is lifted the special lifting beam with adjusting screw should be used, so that the spindle can be made horizontal before lifting into place A spindle which is lifted, even with a slight inclination, is liable to

damage the moving blades against the nozzle or stationary diaphragms. Check the spindle for being horizontal by placing the level on each journal. It will be seen that the spindle is deflected slightly, due to its own weight and that of the wheels. If the work of setting the cylinder and centralizing has been carried out carefully, the level will show the same inclination from the centre of the spindle for each journal (see Fig 10) The turbine rotor is now the datum point for lining-out, and must not be altered in any way whatever.

ERECTING ALTERNATOR AND THREADING ROTOR INTO STATOR

Lift the alternator stator into its approximate position with a liner $\frac{1}{8}$ in. thick between the feet and the soleplates, having first removed the end bells and silencers To thread the rotor into the stator, ascertain if any special apparatus has been supplied for this operation. This will consist of a shoe which is fastened on to the body of the coupling and is carried on rollers,

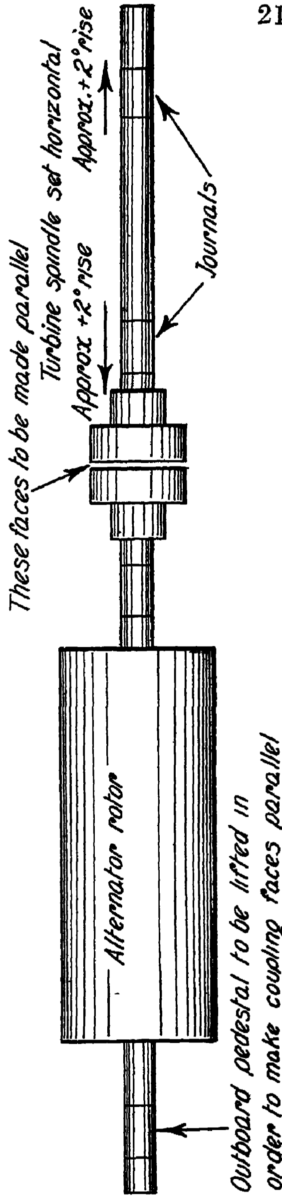


FIG. 10. LINING-OUT ROTORS

journals, passing it into the bore of the stator as far as the sling will permit (see Fig. 14).

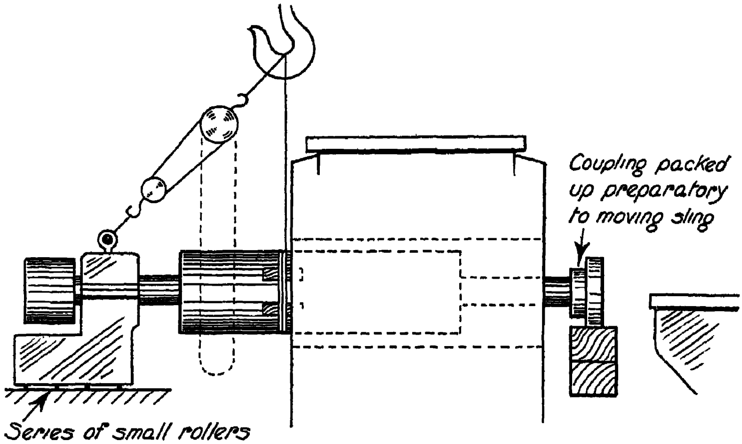


FIG 14 SHOWING ROTOR PASSED INTO STATOR AS FAR AS SLING WILL PERMIT

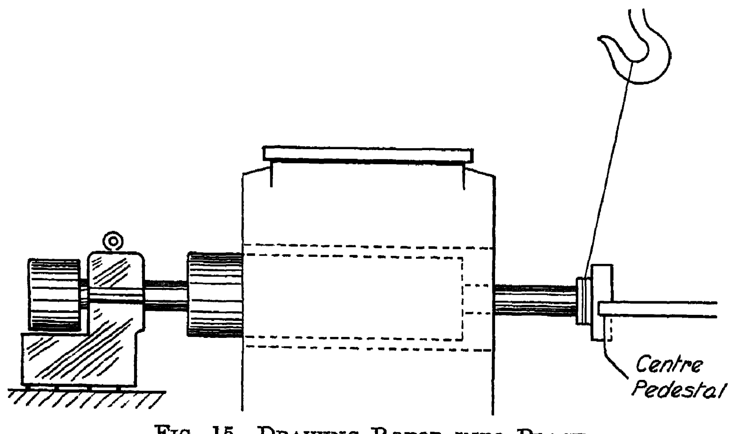


FIG. 15 DRAWING ROTOR INTO PLACE

A series of small rollers is then placed between the outboard pedestal and its soleplate consisting of $\frac{3}{8}$ in. diameter rods, or larger should the air gap permit.

The coupling end of the rotor is then packed up on baulks of timber and the sling moved to this point, dispensing with the chain blocks (see Fig. 15) The weight is then taken and a slight drag put on with the crane. The outboard pedestal is then moved on the rollers towards the turbine by means of a small jack, if it is convenient, or by means of a pinch bar, care being taken not to get too much drag with the crane in case the alternator rotor collides with the turbine spindle. The bearing is then fitted into place, the rollers removed, and the sheets of insulating material previously mentioned fitted underneath the outboard pedestal.

LINING-OUT THE ROTORS

In lining-out the rotors the object is to make the half-coupling faces parallel, and one half concentric with the other. Each half-coupling is usually trued up in the lathe, after assembling on the rotor before leaving the factory, but it is advisable not to take this for granted, so test it for yourself.

The periphery of each half-coupling can be tested by indicating. Fix a dial indicator to a bracket secured to the pedestal with the point resting on the coupling and revolve the rotor slowly any slight out of truth will be clearly seen on the dial This is not so important as the vertical faces of the coupling being true, for the former fault can be overcome when setting one rotor concentric with the other, as afterwards explained It is most important, however, that each vertical face is absolutely true, and if this is found to be otherwise steps should be immediately taken to remedy it, the most satisfactory method being by means of a lathe. Make the vertical face of the alternator half-coupling parallel to the face of the turbine half by altering the position of the outboard pedestal and adjusting the

packers under the soleplate Test each face for being true by checking the faces for being parallel in four different positions, two on the alternator and two on the turbine, each at 180 degrees to the other, care being taken to bring the one half back into its original position before turning the other For example, we will assume that each half is stamped with an 0 to indicate the correct position when assembled; then

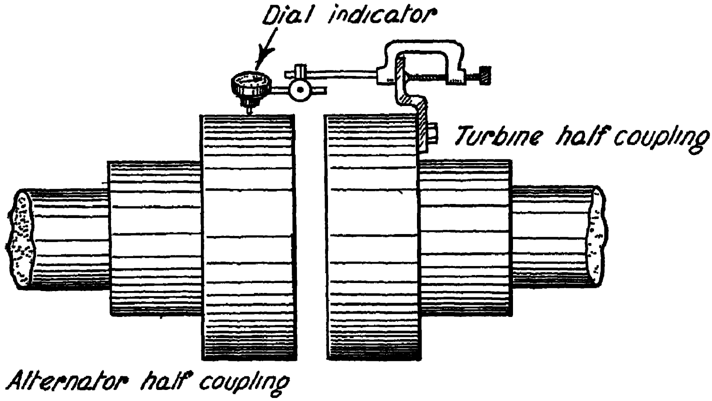


FIG 16 INDICATING A COUPLING

both these are turned so that they are together and on top; the faces are then made parallel and the 0 on the turbine half is turned through 180 degrees, and the faces again checked. This 0 is now turned back into its top position and the process repeated with the alternator half If the faces are true they will be parallel in all positions When checking these faces for being parallel it is inadvisable to use a large number of feelers together, the better method being to make a packing piece approximately $\frac{10}{1000}$th of an inch less than the space between the faces, and use this in conjunction with the feelers. Having made the faces parallel, the next thing is to make the one coupling concentric with

the other Fix a dial indicator to the turbine half with the point resting on the periphery of the alternator half, as shown in Fig. 16, and revolve the turbine spindle slowly to obtain a reading Adjust the liners under the pads of the alternator bearings, until the same reading is obtained on the indicator dial in four different positions, each at 90 degrees to the other. Any adjustment made to number one alternator bearing to obtain this condition must be repeated on the outboard bearing in order to keep the faces parallel.

Should there be any doubt about the periphery of the alternator half being true, when testing for concentricity revolve both spindles together and in the same direction, so that the point of the indicator is resting on the same spot for all readings.

SETTING THE ALTERNATOR AIR GAP

Incline the soleplates carrying the alternator stator upwards towards the outboard pedestal by adjusting the packers in order to equalize the air gap throughout the length of the stator The best method of making this air gap equal is to make a gauge extending from the rotor to the machined spigot face on the stator that carries the end bells, and adjust the packing under the soleplates until the vertical reading is half the sum of the two horizontal ones, repeating the operation at both ends. Do not waste time at this stage setting the alternator stator sideways, as you cannot set it longitudinally until the turbine spindle is located in position and the coupling faces together.

TAKING SIZES FOR PERMANENT PACKERS

At this stage check over the levels and alignment to satisfy yourself that nothing has moved, and take sizes for the permanent packers under the soleplates by

means of calipers and a micrometer, stamping the position of each one with a number corresponding with your machining record to ensure that the correct one is put into its position when machined It is a good plan, in order to reduce the time taken to a minimum for machining the packers, to have one surface already

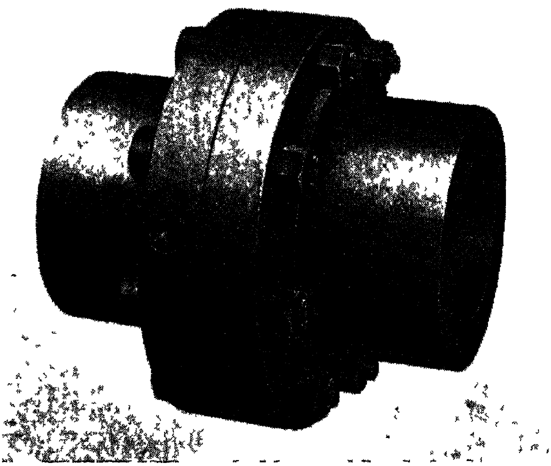


FIG 17 COUPLING BETWEEN TURBINE AND ALTERNATOR

machined, and the local workshop which is to do the work advised approximately when the sizes will be ready, so that they will have a machine available. As soon as the permanent packers are machined, fit them to place by lightly tapping with a hammer, and make any adjustments necessary by means of a flat scraper. Put the holding-down bolts into position as soon as all the packers are in place, and tighten down. Check the levels and alignment to see that nothing has altered, and grout-in the soleplates as previously explained.

MAKING THE EXHAUST JOINT

The exhaust joint can be made during the period that the grouting is setting. This is usually made of red lead putty, unless otherwise called for, when it may consist of a woven asbestos joint specially made to suit the flange. It is important to mix thoroughly the putty, pounding it with a hammer until it becomes soft and free from all lumps, the proportions being approximately two parts of white lead to one of red by weight, adding a little boiled oil to give the required consistency Spread the putty on the exhaust flange of the condenser approximately $\frac{1}{32}$nd of an inch thick and as uniformly as possible, avoiding the use of any string, tape, or wire Fit a bolt in each corner bolt hole of the exhaust flange approximately $\frac{1}{64}$th of an inch less in diameter to act as guides. Place a jack of suitable strength between each stool and its corresponding condenser foot, and lift the shell horizontally until the exhaust flange faces are just touching, making sure that no undue strain is put on the cylinder. Put all bolts into position and pull the faces tightly together.

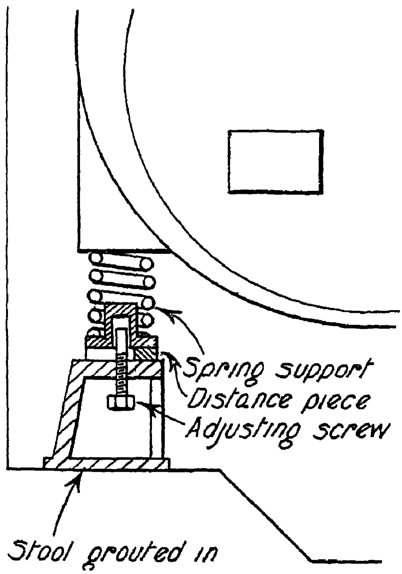


FIG 18 SPRING SUPPORT FOR CONDENSER

All springs for supports are tested before leaving the factory under their designed load, and packing pieces (see Fig 18) are made to give the required compression

when in their final position, each one being stamped with a number corresponding to that on the spring identification tag. Set the face of the stool the correct distance from the face of the condenser foot, as shown on the drawing, by adjusting the packers underneath

Put the springs into position corresponding to the chart or information supplied by the factory, without distance pieces and uncompressed. The prime object of this is to compensate for the unequal weights at either end of the condenser, due tothe water-box in one case and the end cover in the other The spring is then compressed by means of the compression screw, the distance piece inserted, and the compression screw is then slackened off. This is carried out on one foot at a time until all are completed. Slacken off the bolts holding the thrust pedestal and the cylinder to their respective soleplates, in order to see that the condenser has not lifted the cylinder in any way. Having satisfied yourself that all is in order, the stools carrying the springs can now be grouted-in and the atmospheric pipe joint made.

FITTING THE THRUST PEDESTAL EXPANSION WASHERS

The temporary washers placed under the thrust pedestal holding-down bolts can now be replaced by the expansion washers, adjusting each one in the lathe, and scraping the boss of the pedestal foot until a 0 002 in. clearance or that called for on the drawing is obtained (see Fig 8).

BEDDING THE SPINDLE INTO THE BOTTOM-HALF GLANDS

Remove the spindle from the cylinder and lift all diaphragms and cylinder glands into place The spindle is then lifted into position and revolved slowly in the

same direction as it rotates when under steam to avoid the moving blades fouling the stationary ones. The spindle is then lifted, and any places on the labyrinth packings which have come in contact with the hubs of the wheels and gland sleeves are adjusted by means of a specially constructed scraper (see Fig 19). The spindle is then replaced and the operation repeated until it

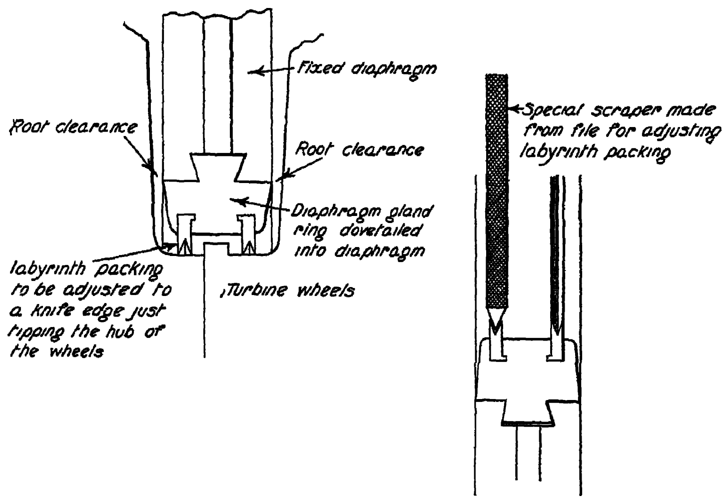


FIG 19 SHOWING ROOT CLEARANCE, ALSO LABYRINTH PACKING AND METHOD OF ADJUSTING SAME

revolves freely It is important not to take too much off this packing when adjusting, but to leave the knife edges of the labyrinths just touching the hubs or gland sleeves. This packing can be clearly seen in Fig 20.

SETTING THE CLEARANCES

The spindle now being free to move in the bottom half glands, the clearances between the exhaust side of the stationary and the inlet side of the moving blades

can now be set, these being located by means of the thrust bearing.

Assemble the thrust bearing in place complete, and should this be of the Michell type the special ring

FIG 20. TOP HALF OF A CYLINDER COVER SHOWING LABYRINTH PACKING

locking pieces for surging pad adjusting screws should be taken off, and the screws tightened up lightly until there is practically no clearance between the thrust pads and the collar, care being taken not to turn the spindle while under these conditions

The clearances between the moving and stationary blades are then set to the drawing It will be found

that it is impossible to obtain exactly the figures called for, so the best mean clearance is obtained working to a limit of 15 per cent either way It may even be found necessary to machine the faces of some of the stationary diaphragms to obtain these dimensions.

Check the clearance at the root of the wheel, as shown in Fig 19. These are usually larger and not so important as the blading clearances, and a greater margin is permissible up to 25 per cent on the small side of those called for on the drawing. Should they be larger they may be ignored It is advisable as soon as the blading clearances are fixed to locate the thrust bearing in position with temporary packing pieces to prevent the spindle from moving laterally Set each paddle wheel gland so that the axial clearances between the race and the paddle wheel are to drawing, and take sizes for the various packing rings to locate them in their correct position, also take sizes for the thrust bearing packing pieces and have these machined to your instructions Set the surging pad screws to the original position, and lock in place by means of the special locking plates.

SETTING THE THRUST BEARING

Set the thrust bearing housing in the pedestal radially to the spindle by adjusting the liners under the housing pads, so that the clearances between the wipers and the shaft are equal all round Check the axial float by assembling the bearing completely and pressing it hard over, so that the thrust pads are in contact with the thrust collar on the turbine spindle The size between the housing register and the grooving in the pedestal is taken in a similar manner to taking the size for a packing ring The bearing is then pressed hard over, so that the surging pads are in contact with the collar and the size taken again, the axial float obviously being the difference between the two sizes It is

important to check this axial float in the manner just described, and not by passing feelers between the pads and the collar with the top removed, as the spherical ring carrying the thrust pads is liable to give false readings The thrust collar and the spherical ring can be clearly seen in Fig 21 on the right-hand end of the spindle. Any adjustment found necessary has to be made by altering the sizes of the washers under the heads of the surging pad screws, care being taken that an equal adjustment is made to each washer, and that the screws are locked in their new position without any undue compression being put on the washer, or the screw slackened off again to suit the locking plate, but that a new hole is drilled or a new plate made if necessary to suit the position of the screw head. It is important to test the axial float, as previously described, after making any adjustment. The packing rings can now be fitted to place, and the top half of the housing left in position to prevent any dirt getting inside.

BEDDING THE TOP HALF CYLINDER GLANDS TO SPINDLE

Having located the spindle in its correct position with the thrust bearing, lift the cylinder cover into place and revolve the spindle slowly It is most essential that the cylinder cover is made horizontal before lifting into position, and that the cylinder guide studs are used Mark the lifting tackle when the cover is horizontal, for this information will be useful at a future date, when the cover has to be lifted off after the tackle has been used for some other purpose The cover is then lifted and the hard places on the labyrinths adjusted as previously explained, and the operation repeated until the spindle revolves freely with the cylinder bolts tightened up Lift off the cylinder cover and take out the spindle, so that the governor and oil pump which

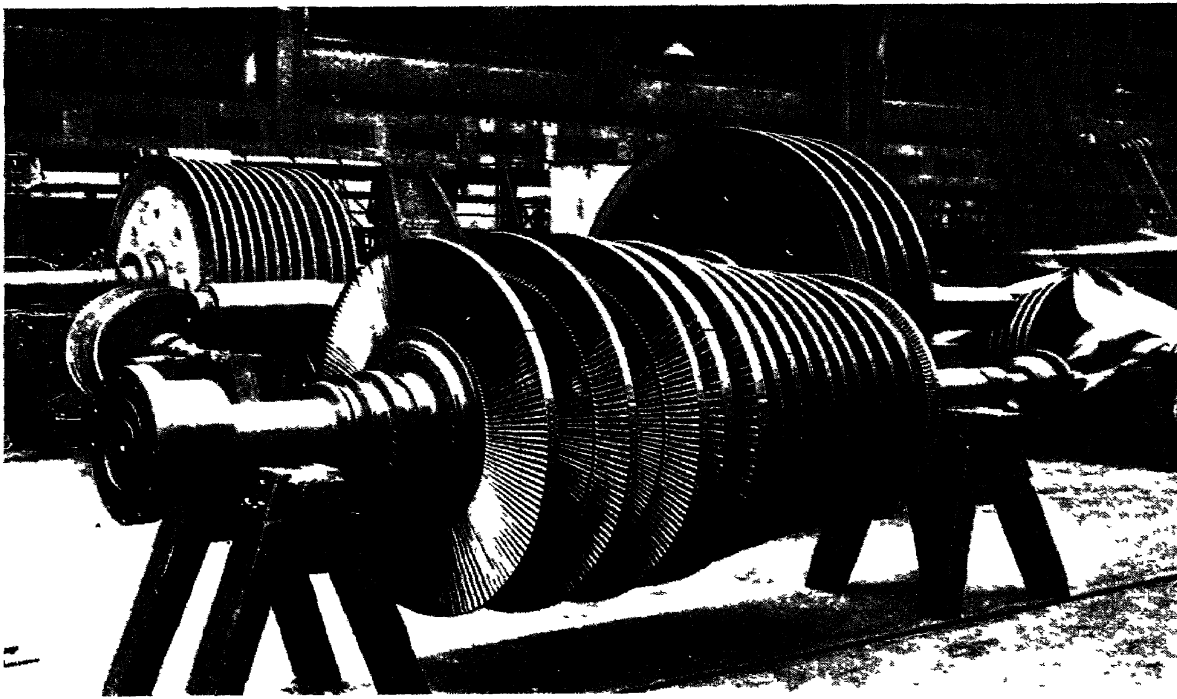


FIG. 21. TURBINE ROTOR

are driven from the turbine spindle can be assembled. Fig 22 shows the governor complete, and also the worm wheel drive.

CYLINDER DRAINAGE

It is important that water does not lodge in the cylinder at any point, for serious damage can be caused

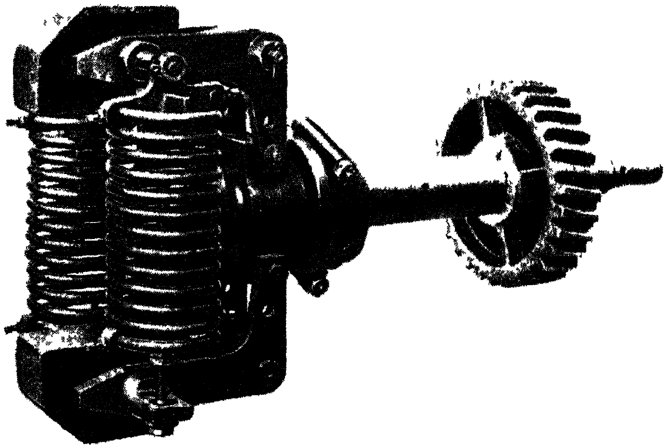


FIG 22 GOVERNOR AND WORM WHEEL DRIVE

by moving blades striking water, or corroding away by standing in it when the machine is shut down, so it is advisable to be satisfied that the designer has given this every thought, or that the workshops have carried out his instruction correctly. This is usually accomplished by permanent drains carried away to the condenser, and by holes drilled in the bottom half diaphragms about $\frac{1}{4}$ in. diameter at the high pressure end, and increasing in size towards the low pressure end of the

cylinder. A simple method to test this drainage is to pour several buckets of water between the diaphragms and also under the nozzle box. Should any water collect, steps should be taken to fit a drain or drill the diaphragms so that the water will rapidly drain away.

ASSEMBLING GOVERNOR AND OIL PUMP

Make the governor spindle revolve freely in the bushes, and press the worm wheel into place It is

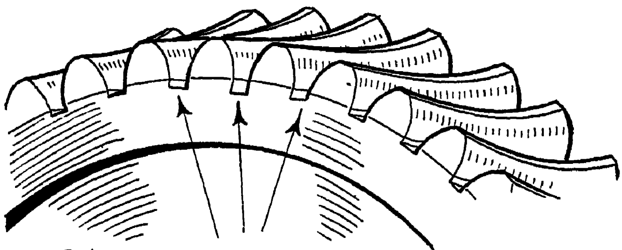


FIG 23 WORM WHEEL FOR DRIVING GOVERNOR AND OIL PUMP

important to chip away the wheel between four teeth beforehand, as shown in Fig 23, to clear the worm, thus enabling it to be drawn off the shaft or the unit removed, as the case may be, when the turbine spindle is in place, marking the position on the side of the wheel so that these four teeth can be turned into mesh with the worm, should it be required to do so

The wheel is now made central with the spindle, and sizes for rings locating it in this position taken. The governor is now assembled with the exception of the springs, which are left off until the travel is marked on some convenient place of the gear connecting the governor with the relay system.

It is important to see that the weights are of equal weight, as any discrepancy may cause the speed to vary Assemble the oil pump, making sure that everything is free and that the clearances are those called for on the drawing, also noting that any air relief or lubricating holes to bushes are drilled. It is important to get the correct thickness of jointing material between the casing and the cover, as one less than that called for on the drawing may cause the pump to seize up, while one of a greater thickness will cause the oil to be by-passed, thus reducing the quantity

BOXING-UP THE CYLINDER

It is necessary to make this a continuous operation, and to enable this to be carried out it is advisable to take out all the diaphragms and nozzle boxes the previous day, also the valve chest can be cleaned and reassembled, provided that suitable blanks are fitted over the inlet and outlet steam passages. Fig 25 shows a section of a valve chest, from which may be seen the various places where foreign matter may lodge. Clean each nozzle box by taking off the nozzles and wiping out with a rag, inspecting the inside of the box for any pieces of scale or loose metal which are liable to become dislodged later Avoid the use of an air pipe wherever possible, as this only drives dirt into corners and inaccessible places, and causes bits to fly about the engine room, alighting on journals and in places already cleaned out.

Blank off the end of each nozzle box as it is cleaned, and cover up with a sheet to prevent any dirt getting through the nozzles, having first locked the tap bolts holding the nozzle block to the box by caulking some of the metal of the block into a fillet provided on the bolt head. It is important not to caulk the bolt head into the block, as the blow from the hammer is liable

to fracture the bolt, causing the head to become dislodged after a time, thus damaging the first row of moving blades It is advisable to prepare beforehand a quantity of suitable sheet metal discs drilled to suit alternate bolt holes for blanking off the nozzle boxes and steam chest as they are cleaned

Clean out the cylinder and lift the nozzle boxes into place, making the joint between the box and the cylinder of material the correct thickness, as called for on the drawing This will probably be $\frac{1}{16}$ in asbestos board or a similar jointing material Assemble steam chest to nozzle boxes on the spring supports, making sure that no undue strain is put on the cylinder This joint is usually a face-to-face joint, and should only be smeared with manganesite and graphite paste. Level up the steam chest by any convenient machined face, or should this have been assembled before work, to the dowels Lift all diaphragms into place, rubbing the rims with flake graphite to prevent corrosion, having first carefully blown them out with a compressed air pipe as far away from the cylinder as possible, inspecting each passage for pieces of wood, etc , which may have got wedged between the blades Clean and inspect the spindle as previously explained and lift into position, locating by means of the thrust bearing. The spindle blades may have been treated with vaseline during some stage of the manufacture or for shipping to site purposes, so particular care should be taken to see that no small pieces of chippings, etc , are adhering to the blades by this medium Make the main cylinder joint with only a mixture of three parts of manganesite to one part of graphite by weight Avoid the use of lead wire or asbestos cord for a new machine, although they may be used to advantage on an old one, where the face has got distorted with temperature or scored due to a leaky joint Lift the cylinder cover into place and

tap the dowels into position, tightening down the bolts, commencing with the four nearest the glands, and working outwards. It is advisable to follow up the tightening of these bolts as soon as the set is warmed up.

Couple up the alternator rotor and lift all bearing top halves into place without bolting down, to prevent any grit getting down the sides of the journals The pedestal covers should also be lifted into place to prevent dirt getting into the oil system.

ADJUSTING THE BEARINGS FOR CLEARANCE AND LOCATING IN PEDESTALS

Bearings are usually machined to size, and the journals machined to size less the required oil clearance, but owing to slight machining errors and the bedding of the bearing to its respective journal, slight adjustments are necessary. Examine the clearance in each bearing by placing three strands of soft lead wire about $\frac{1}{32}$ in. diameter across the journal. The bearing top half is then tightened hard down until a feeler gauge of 0 0015 in cannot be inserted at the horizontal joint, the top half is then lifted off and the lead wire gauged with a micrometer. The thickness of the wire at the top of the bearing should be the sum of the thicknesses of those at the horizontal joint

In arriving at a bearing clearance for this type of machine it is quite satisfactory to allow 0·002 in for every inch diameter of the journal, and should the leads not show this the bearing top halves must be adjusted either by scraping, should they be too small, or by filing the horizontal joint, should they be too large

The bearings having been located in the bottom halves of the pedestals by means of the liners under the bearing pads during the centralizing process, the top pad should be tried for bearing on the pedestal cover. This is done by placing three strands of lead wire

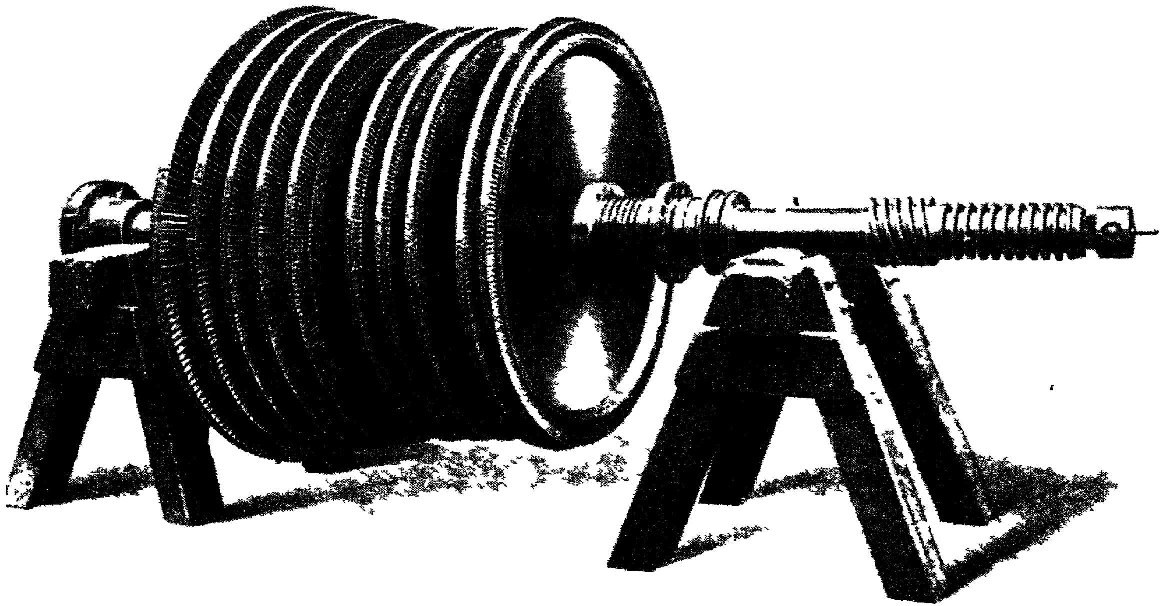


Fig 24 Turbine Rotor showing Spindle Details

across the top pad, similar to that used for the bearing clearances, and pieces about 6 in. long at the centre and each of the four corners of the pedestal The cover is then tightened down uniformly and the leads afterwards taken out and examined.

The difference between the two sets of leads when gauged will mean a liner of that thickness to be added to the top bearing pad, or taken out, as the case may be. As soon as each bearing adjustment is completed, lift the pedestal cover into place temporarily.

SETTING THE STATOR RELATIVE TO THE ROTOR

Set the air gap by means of the gauge extending from the rotor to the machined spigot on the stator for the end bell, as previously explained, when taking sizes for the packers under the alternator soleplates. To set the stator longitudinally the best method is to check the machining of the vertical faces of the end bells to drawing, and lift one half into position at either end, setting the clearance between the fan and the end bell equal at both ends, making sure that the air gap setting is not disturbed. The holding-down bolt holes can now be drilled in the soleplates, having first scribed a line round the feet on to the soleplate in order to detect any alteration of the setting during this operation.

FITTING OIL PIPES TO PLACE

It is essential that all oil pipes are properly cleaned before fitting to place, and the best method is to pass a chain through them until all sand, etc , which is used in the manufacture for bending, and may be adhering to the sides, is dislodged. The pipes are afterwards blasted out with steam and immediately plugged up at either end until required for assembly

Any screwed piping that is used for oil services must

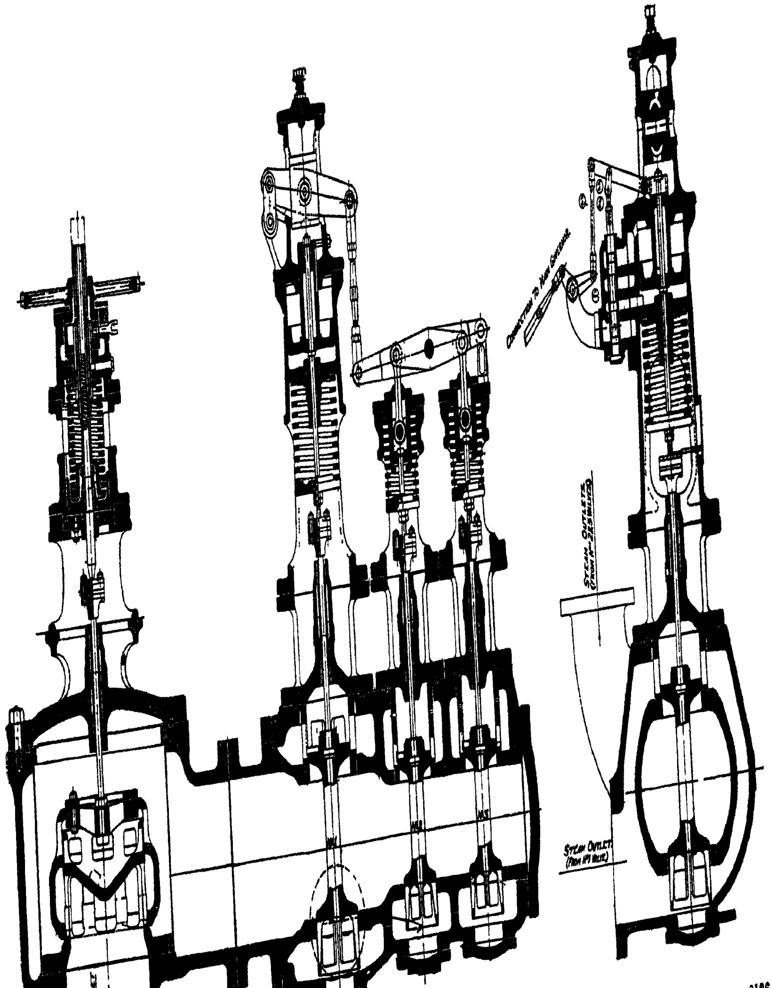


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Fig 25 Section of Turbine Steam Chest

(5575)

be soldered at the joints before passing oil through. Make all oil joints with jointing material used for steam or similar sort of board, having first impregnated it with shellac varnish, making the joint before the varnish hardens, or, if available, by means of a corrugated brass ring filled with a mixture of litharge and goldsize paste. Owing to this mixture setting very quickly, it is advisable to mix sufficient for one joint at a time, making the joint as soon as possible afterwards

SETTING THE AUXILIARY PLANT

Set each line of pumps, etc., on its respective plinth approximately to drawing, but do not grout in, as the final position is located by the pipework. Refer to the drawings to ascertain which pipe line has a template or copper expansion piece in it and locate the pump to the other pipes, keeping it horizontal and its centre line parallel to the centre line of the foundations Fig 26 shows the circulating and condensate pumps, while the air extraction system can be seen in Fig 2.

It may be found necessary to adjust faces of certain pipes to obtain the required setting, and this may be carried out by chipping, should the flange not be very large, in which case it is advisable to machine it if possible When laying a pipe line it is advisable to mark the vertical centre line on each flange, and as each piece is lifted into place this line is set perpendicular by means of a plumb bob, so that when the pump or similar piece is connected up the bolt holes coincide Keep all pipe lines well supported as they are erected, and allow for any expansion, where necessary, by means of roller-block supports or copper expansion pieces Keep all pipework neat, as this can spoil the whole appearance of the set when completed All water joints may be made of rubber insertion Joints under vacuum being made with similar material to

that used for steam joints, but corrugated brass rings filled with red and white lead putty, make a more permanent job for both these purposes Protect the auxiliary plant from injury when it is erected, for being in the basement, tools and heavier articles are liable to get dropped on to it, causing serious damage. Any templets taken for the purpose of machining or making closing lengths of pipe should be handled with great care, and should these have to be sent any distance, should be given into the care of someone who appreciates their importance.

FILLING THE OIL SYSTEM

Fill the oil tank a few inches above the oil strainers, making sure that the class of oil used is in line with that specified by the engineers.

In each flanged joint nearest to the bearing place a piece of fine wire gauze, so that when oil is circulated through the system by means of the auxiliary oil pump, any grit or foreign matter is collected.

Lift off the pedestal covers and the top halves of the bearings and circulate oil through the system, noting that oil is getting to each bearing, the spray pipe to the worm and wheel, and any other parts that are lubricated by this system After circulating for about 2 hours, take out the wire gauze from each bearing and wash it in paraffin, repeating the process until all the foreign matter has been collected.

It is important to cover up the bearings with sheets of clean paper while this cleansing process is in operation. As soon as it is completed box-up the bearings, finally making the pedestal cover joints with soft soap only, avoiding the use of lead wire, paper, cord, etc.

It is an important point to remember, when making this class of joint, that the mixture is spread on very

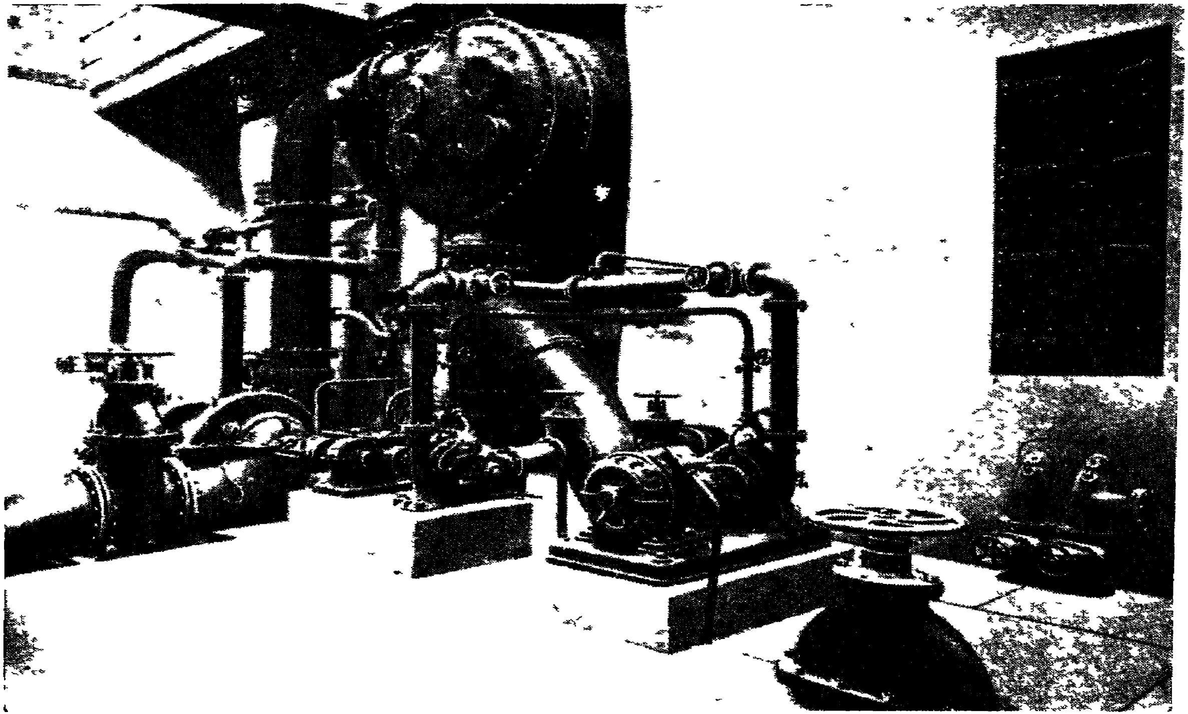

FIG. 26. AUXILIARY PLANT

thinly and evenly, and make sure that there are no hard lumps in it.

FITTING THE BRIDGE GAUGES

During the cleaning process of the oil system just explained, and before the machine is run up for the first time, the fitting of the bridge gauges is carried out These are gauges that record the vertical position of

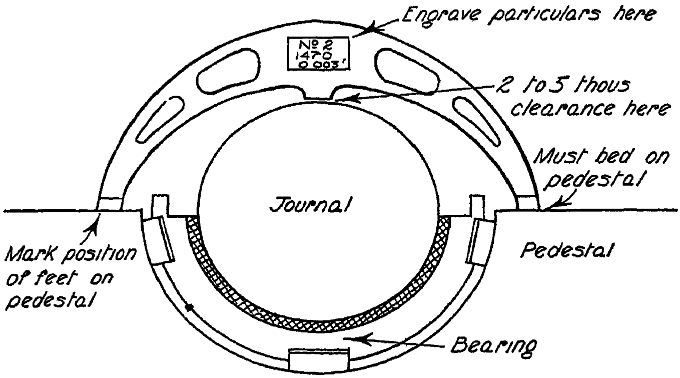

FIG 27 BEARING BRIDGE GAUGE

each journal relative to the horizontal joint of its respective pedestal. The careful fitting of the gauges is apt to get neglected. but it is a very useful thing to know the original setting of the bearing when making periodic inspections during the commercial life of the set, so a little care in carrying out this operation amply pays for itself.

Each gauge should be fitted so that both the feet rest on the pedestal horizontal face, and the clearance between the centre pad and the top of the journal is from $\frac{2}{1000}$th to $\frac{5}{1000}$th of an inch (see Fig. 27). This clearance is afterwards engraved on the gauge along with its number and the serial number of the machine,

the position of the feet being marked carefully and clearly on the pedestal face by means of a fine flat chisel.

Do not stamp the bridge gauge, but get any information engraved, as previously explained, stamping only distorts the gauge after fitting

Impress upon the client the importance of these gauges, and try and persuade him to have made a small cupboard with a glass front, where these can be kept in a convenient place, otherwise they are apt to get distorted and damaged, and may be very misleading

FITTING THE LATERAL MOVEMENT GAUGE

The object of this gauge is to detect any wear of the thrust bearing pads, and it is fitted in a similar manner to the bearing bridge gauge, but instead of the journal the position of the extension spindle on the safety governor, seen in Fig. 24, is recorded relative to the pedestal end cover It is very important when running up a machine for the first few times to take periodic readings on this gauge, especially when applying load, to detect any lateral movement of the spindle.

RUNNING-UP FOR THE FIRST TIME

Test the emergency stop valve by means of the hand tripping gear before turning steam on to the set. Circulate oil through the bearings for about $\frac{1}{4}$ hr. prior to starting the spindle to rotate, to ensure that all air is expelled and that oil is reaching the remote parts of the system Open all drains and warm up the steam chest, leaving all steam chest drains open until load has been applied Lift the governor valve, and open the stop valve until the rotor commences to revolve slowly, when the valve must be immediately shut off, the object of this being to ascertain that the spindle is perfectly free Should it pull up immediately, it is an indication that all is not working freely, and an

investigation should be immediately made before proceeding further. In order to heat the internal parts uniformly the rotor should be kept revolving slowly for about 15 min., bringing it gradually up to speed, taking particular note of the following points—

1 That no undue vibration appears

2. That all bearings are cool.

3. That the oil service, both on the lubrication and relay systems, is properly maintained Adjusting the relief valves to obtain the required pressures.

4. That the thrust bearing is functioning by means of the lateral movement gauge on the end of the spindle

5. That any lifting gear on the governor valves for starting up purposes is cut out of operation as soon as the relay pressure is established.

6. Listen for any indication of the moving parts fouling the stationary ones, by means of an improvised stethoscope consisting of a 6 in. flexible rule gripped between the teeth and placed in contact with the cylinder at different points, the fingers being placed in the ears to deaden any external sounds

Do not take any risks by hurrying the machine up to speed, and if in doubt about any part being satisfactory, shut down immediately and make an investigation

As normal speed is approached see that the governor takes control of the machine. Do not open the stop valve more than is sufficient to operate the machine on normal speed, the reason for this being that should any fouling of the moving parts take place it is immediately indicated by the machine slowing down in speed As soon as you are satisfied that the machine is running satisfactorily, test the safety governor by opening the stop valve and lifting the governor valve with the gear provided Do not run the machine for long periods without load, this period should not exceed 2 hours

Shut down and make any adjustments that may be

necessary to the main and emergency governor, etc., and make the following examinations—

1. Examine all bearings and ease any hard places by means of a half-round scraper

2. Examine the thrust bearing, taking out the pads for this purpose.

3 Examine the worm and wheel for bedding and any signs of wear

4 Dismantle oil pump and examine the wheels and bushes

5. All oil wipers on pedestals should be taken off and any hard places eased, as these rapidly cut into the shaft, causing permanent grooves if allowed to rub.

6 Should the governor tend to hunt, this will most probably be due to the valves having distorted, causing undue friction. These should be taken out and examined, any adjustments found necessary being made with a smooth flat file It may be found necessary to repeat this operation several times before the valves take up their final shape After another run up to prove the adjustments, the machine is ready for drying out the alternator and afterwards for going on commercial load

After the machine has been running on load for about one week the condenser ferrules become slack, due to the oil in the packers having run out, and these should be followed up or the condenser will begin to leak

It is also advisable to take all the oil out of the system and clean the oil tank, as any dirt in the return oil system will have collected here

In drawing this article to a close, the following points cannot be over-emphasized—

1 Cleanliness in all internal working parts and oiling systems

2 Once a piece is cleaned, to blank-up any port immediately

3 Avoid forcing anything—stop and think

4 Avoid leaving ends of pipes open for tools, etc., to get placed inside.

5. Use wooden plugs with large heads for blanking pipes and holes up to 4 in diameter, larger pipes should be blanked with suitable discs Avoid the use of cotton waste or plugs made of rag

6. Avoid the use of cotton waste for cleaning purposes, it contains grit.

7. Do not lift a piece without first having approximately estimated its weight and chosen a suitable sling, a table giving safe loads for ropes and chains can be found in most engineers' handbooks.

8. Do not take risks when running-up for the first few times, until you get to know the characteristics of the machine; if in doubt, shut down and make an investigation

9 Avoid the use of doubtful lifting tackle.

10. Keep complete records of all clearances and levels

11 Keep the pipework neat, and the smaller pipes out of sight as much as possible

12 Keep the work clean and tidy throughout the erection.

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